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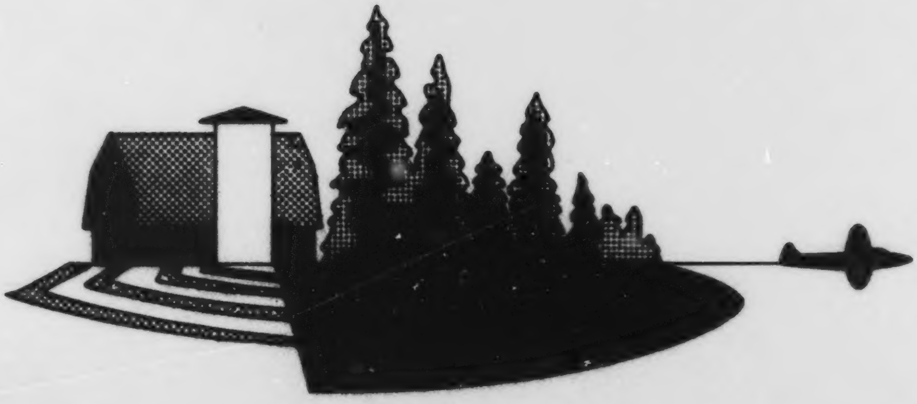
SYMPOSIUM ON THE FUTURE ROLE OF AVIATION IN AGRICULTURE



THE ASSOCIATE COMMITTEE ON AGRICULTURAL AND FORESTRY AVIATION

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PROCEEDINGS

SYMPOSIUM ON THE FUTURE ROLE OF AVIATION IN AGRICULTURE

THE ASSOCIATE COMMITTEE ON AGRICULTURAL AND FORESTRY AVIATION
NATIONAL RESEARCH COUNCIL OF CANADA

September 1984

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Peter W. Voisey
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SYMPOSIUM: The Future Role of Aviation in Agriculture

FOREWORD

The Symposium was organized by the National Research Council Associate Committee on Agricultural and Forestry Aviation (ACAFA) in recognition of the increasing importance of aerial operations in agricultural production. The objectives set for the Symposium were to review the technological progress made over the past two decades assess the current situation, develop a view of the future potential for this industry and define the actions needed to realize this potential. The two-day Symposium was the first of its kind, with a focus on agricultural applications, held in Canada.

The Symposium was comprised of 9 technical sessions where invited speakers presented 25 papers. In addition, 11 submitted papers were displayed at poster sessions covering both agricultural and forestry applications. These proceedings include both the presented and poster papers. The Symposium was attended by 157 people representing a wide range of interests including federal and provincial governments, universities, industry, applicators and operators, aerial operator and farm associations and farmers.

For reference, complete lists of: the 166 Symposium registrants; the members of the ACAFA Committee; and the Symposium organizing committee are included in the Proceedings. These lists include complete addresses, etc. providing a useful source of contacts of "who is who" in the agricultural aviation business.

A comprehensive program was prepared for the Symposium which included abstracts of most of the papers. Copies of the program are still available from:

Engineering & Statistical Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario K1A 0C6

Each of the presentations is numbered according to the Symposium program in these Proceedings.

Aerial applications in agriculture is a complex topic involving a diversity of interests. The technology that must be covered ranges from basic biology and agronomic practices to physics, aerodynamics and aircraft operations. Aircraft are used for a variety of agricultural operations with aerial spraying of chemicals being the predominant use followed by aerial seeding, application of granular materials and fertilizer and aerial surveying. The use of aircraft in agriculture is further complicated by the need to impose chemical and aircraft regulations involving federal, provincial and municipal jurisdictions. The diversity of the topics presented by the speakers and the range of interests of those attending the Symposium reflect these complexities.

In editing the Proceedings, I have imposed a minimum of change to the authors' material. Changes made were minor and only in the interests of clarity. In the interests of a free exchange of information, no constraints were placed on the speakers' presentations or on the material included in these Proceedings. Thus it would be incorrect to assume that the opinions expressed by the authors represent an official position of the agency represented by these individuals. The reader should confirm the situation with the respective authors before making such an assumption.

The editor reached some personal conclusions as a result of the information presented during the Symposium, and it is perhaps appropriate to provide these views.

1. Aircraft applications have grown over the past two decades to a relatively small (in terms of total agricultural production) but vital component of Canadian farm operations. The business has "settled down" into an integral component of many farmer's yearly operations, aircraft are relied upon to achieve efficient crop production. Farmers are utilizing aircraft or aircraft operator services on a routine basis for spraying and seeding. Granular material and fertilizer applications by aircraft is also increasing.

2. Accurate statistics on aircraft use in agriculture are sparse, however, it is clear that aerial spraying is the predominant use. Generally, the USA and Canadian statistics for agriculture align relatively closely. Thus it is unusual to find that in Canada, 5- 10% of spray work is done by air, whereas in the USA, the national average is 25%. More accurate Canadian statistics would be useful to determine the exact situation.

3. It was generally agreed that there is an excellent potential for agricultural aircraft operations to increase in Canada. Some factors are:
   a) the small portion of crops currently sprayed by air could be expanded;
   b) forecast long term increases in agricultural production will expand the requirements for aircraft;
   c) aircraft provide advantages for bringing marginal land and pastures into production;
   d) the use of aircraft for seeding and fertilizing is likely to increase.
   e) aircraft offer the key advantage of speed and timeliness in treating crops for both routine and emergency operations.

4. Although there have been technological advances in aircraft and the spray systems they carry, as well as new chemicals and biological technology, the basic principle underlying the operation has not changed for more than 30 years. The process still relies on pumping liquid chemicals through nozzles to generate a spray of droplets.

5. The predominant concern of operators, farmers, environmentalists, government agencies and the public is drift from aerial spray operations. While aerial spraying may not be the major cause of the total amount of drift, the high visibility of the aircraft make it the perceived culprit. The expansion in aerial spraying achieved to date has increased drift concerns and any future expansion will certainly lead to greater negative reactions. Thus drift must be viewed as the primary problem requiring action. In the long term, this negative aspect will increasingly become an impediment to expansion. While much work has been done towards minimizing drift, the existing information does not appear to be properly disseminated and used to advantage. New monitoring equipment is available and this should be accessible in Canada so that accurate drift data can be obtained and aircraft systems calibrated to achieve optimum efficiency.

6. Efficacy of aerial spraying is still not optimized. While farmers see positive results, it is still not understood exactly how much chemical should be applied to maximize the efficiency and efficacy, and minimize costs and environmental impacts. The optimum droplet size, density of droplets per hectare and the ideal impact point on the pest have yet to be delineated. Evidence suggests that the amount of chemicals applied could be greatly reduced if such information was developed. This requires basic physical R&D on droplet generation and dispersion from aircraft backed by biological research on pest control.

7. Aircraft provide a major advantage for agriculture, namely, timeliness. The aircraft can apply chemicals, seed and fertilizer:
   a) when wet ground conditions prevent the use of field equipment;
   b) over large areas in a short time;
   c) to control pests on standing crops where field machines would cause crop damage under both normal and emergency situations.

   Timeliness is of great importance for Canadian crop production since most of the cropping regions are at the climatic margins suitable for crop production. Thus a matter of days in timing a farm activity may have a large impact on productivity or even viability of the crop.

8. Ground and air spraying activities should not be treated as separate issues. Much of the technology has a common base (i.e. the spray nozzle and chemicals used) and both generate drift. Ground spraying equipment has improved in terms of drift control and speed of operations. If aerial spraying is to meet this competition, improvements (economic and efficacy) must be made.

9. The economics of aerial operations are complex and require study to provide advice to farmers and assist them in developing business plans.

10. Regulations covering both pesticide use and aircraft operations are generally viewed by farmers and operators as impediments but a necessary evil. There is concern that over-regulation could destroy the industry which would be a serious loss. Both chemical and aircraft regulations are currently undergoing changes. A positive aspect is that the government agencies responsible are increasing their efforts

to consult with all those concerned in the development of new regulations. This opportunity should be used by farm and operator organizations to ensure that their views are considered.

11. Historic and recent decisions in the courts have created a difficult situation for those in the aerial spray business. This can only be overcome through changed legislation.

12. A recurring theme throughout the Symposium was the lack of R&D effort in Canada to support agricultural aircraft operations. There is a need to establish a coordinated research program. The predominant gap is the work on the physical side (droplet generation, physics and aerodynamics) which should be expanded. There is a need to coordinate the physics/aerodynamics work with biological research and to establish a national program of field efficacy trials.

Peter W. Voisey
18 May 1984

Paper No. I-A

CHAIRMAN'S OPENING REMARKS

W.C.E. Loftus
Chairman, ACAFA
P.O. Box 669
7 Edward Street
Manotick, Ontario
KOA 2N0

ABSTRACT

In many parts of the world the part played by aircraft in agriculture is vital and it is important that this is the first symposium of its kind to be held in Canada.

The structure of the Symposium is a bit different from most since it deliberately sets out to look back over the years to make comparisons with the present and to look forward to find directions for the future, not the least being defining areas needing further research.

The Committee has endeavoured to get representative and stimulating speakers to cover all the significant aspects of the subject and to provide the opportunity for discussions and the exchange of ideas between attendees. In addition, there will be poster sessions throughout the span of the meetings which focus on forestry as well as agricultural applications.

On behalf of the committee members of ACAFA and the NRC I would like to extend a welcome to everyone attending this symposium. We are pleased that so many of you have come, some quite long distances and we hope that your journey, long or short, will prove to have been worthwhile.

The emphasis of this Symposium is on the part played by aviation in agriculture, past, present and future. It also marks the beginning of much closer research co-operation between Agriculture Canada and the National Research Council.

The reasons for holding gatherings such as this one are either to impart new information, or to collect new ideas and seek guidance for the future. While it is going to do something of both, the real bias of the Symposium is towards the latter. ACAFA, as an advisory arm of the NRC is always trying to determine how best to advise on research efforts, so as to get the best effect. Although not very evident of late, it has been known for a very long time that without research, an organization, or society as a whole, withers and dies.

The decision to make a review of the subject an integral part of the presented papers was made with definite aims in view. History and experience should have taught us by now that it is advisable to periodically stop and take stock, no matter what the subject, so we at least have a chance to ensure that our perspective has not become clouded or our sense of proportion lost before pressing-on. We must also have learned that solutions to problems are rarely as simple as first appears. Radically different solutions are sometimes needed to solve very closely-related problems and what is correct and acceptable at one time may very well become unacceptable when times and circumstances change - and vice versa. As an example we might cite much-reviled DDT which is, nevertheless, generally credited with saving 100 million lives.

As far as retaining our perspective, consider when two airliners happen to pass within about half a mile of each other at substantially the same height and in opposite directions. This is known as a 'near miss'. It causes a slight uproar, there is an investigation, the 'media' tend to inflate it into a narrowly-averted disaster and many people get nervous about flying, and so on. Yet, the same 'scared' public will, twice daily and in their millions cheerfully drive along ordinary highways at 60 mph, three feet away from another two ton mass going the opposite way at the same speed or more, most definitely at the same level, driven by an amateur, sometimes on wet or icy surfaces - and not give it a second thought!

The cost and effort of solving problems arising from man's desire to harness or modify nature's apparent course varies according to the wealth, sometimes profligacy and perceived need of society. At some time, however, an account has to be rendered. The desirability or urgency, cost and importance of what is being done has to be related to what society can afford, or it has to be equated with economic, or even physical survival.

It is easy to look back over a twenty or thirty year span and pick out the errors of the past. It is so easy today to condemn the too-great dependence on certain chemicals - or even all chemicals, for control; the criticism may be of the small effectiveness of a then - new application technique, or even the whole principle of application. Perhaps all that is needed is a more balanced outlook.

Selective predators for crop pests were introduced into North America more than 100 years ago, long before the widespread use of chemicals became commonplace for this purpose. It was not all that successful, but that does not detract from the reasoning behind the original idea. Perhaps if we do stop and re-examine the situation from time to time we shall avoid making the same mistakes and reinventing the wheel.

From this 'review' approach it should be possible to think in terms of benefits accrued. After all, the only justification for developing and using special equipment and techniques is success. The only measure of success is how closely the goals are reached, so it is necessary to not only know the goals but to comprehend their significance. There are a number of reasons why crop yields, for instance, have to be increased. The reasons include, simple economics, profit margins, the effects of scale, export markets, competition from foreign producers or just a simple need to meet the demands of a growing population. Consequently, society's and the individual's actions may be prescribed by what is - not just seen as - important at the time. This is not 'situational ethics' but pragmatism in its most real sense.

During the years of ACAFA's existence, it has become obvious to its members that there are many gaps in the industry's knowledge about even the most elementary factors which are part of every aerial and ground application. It follows that a lot more research, fundamental as well as applied, is required before the whole process of application technology is completely understood. It also follows that this has to happen for the industry to become fully effective, efficient and socially acceptable.

There is always a risk that some people can convince themselves that taking short cuts or ignoring the inherent dangers of disobeying practical limitations and rules is justified. This outlook is, of course, deplorable and unacceptable but if the individual sees survival at stake in his 'predicament of the moment', are his actions so hard to understand? Can we also be sure that ever-stricter rules are going to change things? We know that weak regulations spell disaster and over-regulation is equally catastrophic. Success and harmony, and the sense of respect, lie in the predication that regulations and laws are tempered with comprehension.

The advantages which other modern technologies can bestow on our industry must not be ignored either. It is not too difficult to visualize the benefits which can come from using composite materials, miniaturized avionics and micro-processors. In terms of weight saving, accuracy of deposition, reduced corrosion, bigger payloads or better power-to-weight ratios, safety, their impact is great. If these innovations can be coupled to complementary advances in the biological and chemical fields the industry would be able to make a quantum leap forward. Such innovations would have to be justified economically, of course. Or would they?

Lastly, there is the human aspect of it all. The total of all our science and understanding, our technology, economic yardsticks and pressures finally comes to rest in the hands and judgement of ordinary individuals. If they are not highly trained, highly principled, highly motivated and able to exercise good judgement - then all is for naught. Because, when our research, development, testing, approvals, calculations and safeguards have all been refined and done, the final arbiter is the pilot's finger which squeezes a simple button. Perhaps the human element should be first on the list, rather than last.

Now we come to the real beginning of the Symposium, but before the first speaker is introduced it is necessary to spend a moment or two on the human element. I would like to thank Agriculture Canada and, in particular, Mr. Peter Voisey and Mrs. Martha Howey. Without their unstinting efforts the Symposium would not be the well-balanced, orderly sequence of events enumerated in your programmes. Thanks are also due to the Saskatchewan Research Council, the Saskatchewan Department of Agriculture, the National Research Council and members of ACAFA. The people concerned have all contributed to us being here today. We are very gratified that some twenty-four speakers are reading papers and if that is not enough, there are the contributors to the poster sessions.

The programme is a full one, you have a busy time ahead so, once again, thank you for coming and we hope you will have a stimulating and enjoyable two days.

Paper No. I-B

INTEGRATED PEST MANAGEMENT

D.J. Madder and F.L. McEwen
Ontario Agricultural College
University of Guelph
Guelph, Ontario N1G 2W1

ABSTRACT

Despite the use of intensive control techniques, insects, weeds and diseases reduce agricultural production in North America by approximately 45 percent. The importance of this loss will increase as the profit margin in agricultural production decreases and as pressures of increasing world population lead to greater demands upon agriculture. The most efficient means of reducing this loss in most situations has been through the use of pesticides. Pesticides will continue to be the most important method available for practical pest control, but they will be used more and more as part of a pest management program. The goal of integrated pest management programs is to produce the best crops possible on a long-term basis, with minimal deleterious effects on the producer, consumer and the environment. Pesticides will be used in conjunction with cultural, genetic, biological and legal control techniques to produce the most efficient integrated pest management program possible. Only minor effects can be expected to occur in the foreseeable future on aviation in agriculture due to the implementation of these programs. However, in specific instances, the use of aircraft will provide the rapid response necessary for the optimum timing of pesticide treatments.

INTRODUCTION

The main competitors with man in the production of food and fibre are insects, weeds and diseases. Preharvest losses due to these pests in North America are estimated to be about 37%, even with the use of the most modern pest control technology. Insects account for 13% of the losses, plant pathogens 12%, and weeds 12%. Postharvest losses are estimated to be about 9%. Thus the total losses to pests are estimated to be more than 45% (Schwartz & Klassen, 1981). While it is unrealistic to believe that all of these losses could be eliminated, the magnitude of the losses now sustained must be reduced. To help achieve this, crop protection in recent years has moved to a philosophy of integrated pest management (IPM).

There are many definitions which have been used for the phrase "integrated pest management" (Smith & Reynolds, 1966, 1972; FAO, 1968; Van den Bosch *et al*. 1971). To clarify this discussion, let us use a very simple definition......integrated pest management is the use of the best possible combination of methods to reduce and maintain pest populations below a level that would cause economic damage. It is based on a principle of optimum rather than maximum pest control. It constitutes a major component in an agricultural production system which will allow sustained agricultural production with minimal deleterious effects on the producer, consumer, the agroecosystem, and the environment in general (Flint & Van den Bosch, 1981).

HISTORY

The history of IPM does not start with the coining of the phrase in the early 1950's. Rather the concept has evolved from the earliest attempts of man to control his major competitors for food and fibre (Newsom, 1975). For thousands of years, man could do little about this competition except to appeal to the power of magic and a variety of gods. Through empirical "trial and error" experiences, a variety of pest control methods were developed.

Pest control methods until the late 1800's included a variety of cultural and mechanical control methods but primarily relied upon the natural control of pests, i.e., primarily climate and natural enemies. Those factors which were used included: sanitation, tillage, crop rotation, time of planting and/or harvest, trap crops and very primitive pesticides (Riegert, 1980). Usually these methods did not provide adequate control and the total loss of crops was not uncommon. Natural controls could not be relied upon to provide consistent control and often could not maintain pests below economically significant levels. As a result, in the late 1800's and early 1900's, research to find more effective control methods focused on the development of plants resistant to attack of insects and diseases, the use of predators and parasites for insect control, and the use of inorganic and botanical pesticides. Due to the relatively low efficacy and significant cost of the pesticides, they were not relied upon as the sole pest control method. An example of a control program recommended in 1922 for the cotton boll weevil (Newsom, 1975) included a variety of controls:

1. use of early fruiting, prolific, rapidly maturing varieties and the appropriate cultural practices to produce a crop during the shortest possible time;
2. use of trap crops of extra-early maturing varieties to concentrate overwintered boll weevils on a small percentage of the total acreage;
3. spot treatment with calcium-arsenate dust of the relatively small areas into which overwintered boll weevils tend to congregate, in order to reduce the amount of acreage requiring treatment;
4. a system of scouting at weekly intervals for population assessment in order to employ the principle of economic thresholds when it was necessary to use calcium arsenate to suppress populations;

5. imposition of the hazard of food shortage on the potential overwintering boll weevil population by harvesting the crop and destroying crop residues as early in the season as possible;
6. use of land clearing and controlled burning to reduce the area of favorable hibernation quarters.

Although this control strategy is much less sophisticated than many used today, it rests upon many of the principles now embodied in IPM. Unfortunately, many of these controls were not without significant deleterious effects (Glass, 1975). Tillage procedures for insect and weed control, and the destruction of hedgerows to eliminate refugia for pests left land susceptible to erosion. The injudicious use of pesticides led to the destruction of natural controls and significant long-lived residues in the environment.

The discovery of the toxicity of a variety of synthetic organic compounds to insects, weeds and diseases in the late 1930's and 1940's was the start of a new era in pest control. In 1939, the insecticidal nature of DDT was discovered, DNOC was developed as a selective herbicide and fungicide, and in 1944 the herbicidal nature of 2,4-D was discovered (McEwen & Stephenson, 1979). Since that time a remarkable variety of synthetic organic pesticides have been developed and used. The success of these compounds was immediate. They were inexpensive, effective in small quantities, easy to apply in a wide variety of formulations, and toxic to a wide spectrum of pests (Muir, 1978). The application of pesticides, a practice which was confined until the late 1940's to high unit-value crops (primarily orchards, vegetables and cotton) became commonplace in almost all agricultural crops.

The use of pesticides has resulted in substantial increases in quality and quantity in food production and perhaps even more significantly helped to stabilize agricultural production at a high level of productivity. The development and adoption of high yielding cultivars of row crops would not have occurred without pesticides. Many of the new cultivars are highly susceptible to attack by insects and diseases, and weed competition must be reduced if their potential for high yields is to be realized (Pimental & Pimental, 1978).

The new pesticides available in the 1950's and 1960's affected also the attitudes of many who were involved in research and use of pest control techniques. Where previously methods were focused on reducing pest populations to tolerable levels, the new goal became eradication. The pesticides were so effective that many of the old pest control measures (cultural, mechanical, biological, host resistance) were discarded (Smith, 1978; Newsom, 1975). Monitoring of pest populations was not performed and pesticides were often applied as prophylactic treatments whether there were pests present or not. Rigid spray schedules were, and still are, in use on some crops.

Unfortunately the excellent pest control provided by the synthetic organic pesticides has not been attained without significant problems: 1) resistance to pesticides, 2) development of new pests, 3) pesticide residues in the environment, 4) substantial increase in pest control costs, 5) human health concerns (NAC, 1975). It has been these problems which have led us to the implementation of IPM systems. Many of these problems are still of significance, therefore each will be discussed briefly.

Pesticide Resistance

One of the earliest problems associated with the intensive use of pesticides was the development of pesticide resistance. This was not a new problem, resistance was documented well before the use of synthetic organic pesticides. For example, resistance by the San Jose Scale to lime sulphur was documented in 1908. Resistance to the synthetic organic insecticides, however, developed very rapidly, in part, as a consequence of their high efficacy and persistence; the very factors which made them excellent pest control products (Georghiou, 1980). DDT was in use only a few years in Italy when, in 1948, resistance developed. Since that time resistance has been reported to specific insecticides, fungicides, herbicides and rodenticides. The grower's response to the development of resistance has been first to increase application rates (and hence costs), and then to switch to a new pesticide until it is also no longer of use. Some refer to this as the pesticide treadmill. This treadmill may come to an abrupt end as fewer new pesticides, especially insecticides and fungicides, are being developed and registered (Whetstone, 1978).

Development of New Pests

Many potential pests of our agriculture production systems are kept below economically significant levels through the actions of abiotic and biotic natural controls (Van den Bosch et al. 1982). A key component of these controls for insects are predators and parasites, many of which are insects themselves. When broad spectrum insecticides are used in crops, these predators and parasites are often killed. As a result, species which were previously controlled by natural enemies become significant pests. This has occurred with a variety of phytophagous insects and mites, especially those with high reproductive rates (eg., two-spotted mite, aphids) (MacPhee et al. 1976). Fungicides used to control diseases of crops may reduce the incidence of pathogens of weeds and insects or alter the agroecosystem to actually favour other pathogens in the crop. The destruction of natural enemies has also allowed the rapid resurgence of target pest populations, often to levels higher than before the pesticide treatment (Huffaker & Messenger, 1976).

Pesticide Residues in the Environment

The fact that the use of residual organic pesticides might cause chronic damage to the environment has been the subject of public discussion (Carson, 1962) and considerable research (McEwen and Stephenson, 1979) for the past thirty years. In some instances residual chlorinated hydrocarbons have resulted in significant damage, especially in aquatic environments. The phenomenon of biomagnification of specific chlorinated hydrocarbon pesticides has been well documented and has resulted in reproductive failures in some species of fish and egg-shell thinning in specific predaceous birds (peregrin falcon, sparrow-hawk). As a result much has been done to restrict or eliminate the use of many of the residual pesticides in North America. However, concern still exists concerning possible chronic effects of pesticides in the environment

Increasing Costs of Pesticides

During the 1950's and 1960's, pesticide costs did not amount to a substantial proportion of input costs in agriculture. However, with the advent of the energy crisis in the 1970's, the costs of the petroleum-based pesticides increased dramatically along with the costs of the equipment and fuel required to apply the pesticides (Pimental _et al._ 1978). As a result, pesticides have become a significant cost in the production of many commodities. With profit margins in agriculture being reduced and at times negligible, the costs of pesticides are significant (Metcalf, 1980).

Concern for Human Health

Pesticides are of necessity toxic to biological systems and thus are, to some degree, toxic to man. Levels of toxicity range from highly-toxic to compounds which are less toxic than normal foodstuffs. The use of pesticides has always had some user risk.

Despite this, with intelligent use and care, pesticides can be used without direct user illness. A more difficult quesion remains; that of the potential long-term effects of very low residues found in food products (Davies, 1981). The recent concern over the use of specific fumigants (EDB) in stored products and milling operations has led to the elimination of their use. This is a concern which will continue and will only be reduced through reductions in pesticide use.

IPM TECHNIQUES

The above factors have led to the development and implementation of IPM programs which use a combination of pest control techniques (Glass, 1975; Perkins, 1982). There are four basic types of control measures which can be used in IPM systems: 1) biological control; 2) cultural control; 3) host resistance; and 4) pesticides.

Biological Control

Many of our worst pest species are not native to North America, but have been introduced from other continents. As such, they have been removed from their natural enemies. Many successes of the "classical biocontrol technique" have been achieved by introducing the natural enemies of these pests into North America (Caltagirone, 1981). This technique has been used with some success against both insects and weeds. Many introductions of natural enemies have resulted in successful establishment, but relatively few have, by themselves, reduced the pest populations below economically significant levels. Therefore, complementary control measures are used to further reduce pest populations.

Pathogens may hold the greatest long-term potential as biocontrol agents (Kurstak & Tijssen, 1982). Several pathogens (bacteria, fungi, nematodes) are registered for the control of insects. Viruses also have a great potential as insect and weed control agents, although the registration of these agents for pest control on food crops will be difficult (Summers *et al.* 1975).

Cultural Controls

The term "cultural controls" is used here to refer to any crop management practice which may affect pest populations. These methods are usually low in cost and provide long-lasting, but less dramatic, effects than other control methods. Often these methods are prevenative rather than curative. Included are such factors as crop rotation, vitality of the crop, timing of planting and harvest, sanitation, destruction of alternate hosts, and the use of certified pest-free seed (Stern *et al.* 1976). Tillage has in the past been used as an effective control measure for weeds and some insects. However, the resulting effects of erosion may be more detrimental than the benefits provided.

Host-Resistance

Host-resistance has been and will continue to be a very effective measure for preventing losses due to plant diseases and some insects (Pathak, 1970, 1975). As in the case of cultural and biological controls, host-resistance by itself may not provide adequate control of an insect or disease problem.

Pesticides

Pesticides have been and will continue to be a major component of pest control systems. The use of selective pesticides, timed for maximum efficacy and minimum deleterious effects on natural enemies and the agroecosystem, provides a higher degree of control than can be obtained by other control methods (Metcalf, 1980). Almost all IPM systems currently in place or under development make use of selective insecticides and fungicides. The increased use of herbicides is expected as reduced tillage practices are incorporated into more production systems.

IPM PROGRAMS

IPM programs may use one or any combination of the pest control techniques discussed above. The decision as to which control measure to use, and when to use it is based upon economics, the control methods available, and pest monitoring information. Pest monitoring is the method used to collect environmental and biological data from the fields (Whalon & Croft, 1984). A variety of weather data (soil and air temperatures, leaf wetness, quantity of precipitation) is monitored to predict the development of insects and weeds, and the infection periods for diseases. Usually this information is used on an area-wide basis. However, to determine the pest incidence in individual fields, these data must be augmented by additional information gathered by trained personnel (scouts) visiting each field. Typically high unit-value crops require much more field monitoring than low unit-value crops. In vegetable crops and orchards, monitoring may be as intense as three visits per field each week, while in field corn one visit in two weeks may be sufficient. Typically the pest management scout walks the field or orchard looking for problems, checking traps, or making direct observations of the crop itself. The information gathered includes: the identification and mesurement of the incidence of insects, weeds and pathogens; monitoring crop development and vitality; and virtually anything that will affect the pest control decision.

The actual decision to use a specific control method is based upon economic thresholds (Mumford & Norton, 1984). When the incidence of diseases, insects or weeds exceeds a level which will result in economically significant damage to the crop, a control measure is recommended. Economic thresholds are influenced by such factors as: crop value, crop vitality, nature of the pest damage, cost of the control measure and efficacy of the control measure. The development of thresholds used in IPM requires years of research followed by careful use and refinement in operational IPM programs (Poston et al. 1983).

IPM programs, in varying degrees of sophistication, are being used in a variety of crops throughout North America. By far the largest scale operations in North America are in cotton production where very large regional programs are conducted. Orchard and vegetable crops have also had IPM programs introduced in many regions. The oldest IPM program in existence was implemented in apple production in Nova Scotia in the mid 1950's (Whalon & Croft, 1984). IPM has been implemented in cotton, orchards and vegetable crops first, primarily due to their history of intensive pesticide use. As a result, many of the problems associated with the intensive use of residual pesticides occurred in these situations. Typically, IPM programs in orchards, vegetable crops and cotton involve: 1) preseason instructional sessions with growers; 2) pest monitoring scouts who monitor the fields, and recorded weather data; 3) a supervisor who relates the pest monitoring information to potential crop loss, and 4) a system to relay advice to the grower. Depending on the sophisitication and directives of the program, the raw data may be relayed directly to the grower, and/or specific recommendations can be made by the supervisors.

With the exception of herbicides, pesticides have not been used intensively in field and forage crops. As a result the problems discussed above have not, or have been very slow to develop. Thus, there has been less urgency to implement IPM in these crops. In addition, their low unit-value has not allowed the implementation of the labour-intensive IPM systems used in orchards, vegetables and cotton. Recently less intensive programs have started to be implemented in field and forage crops, either by government or by private consultants who provide "crop management" services. These consultants provide IPM advice along with soil analyses, and other services.

IPM BENEFITS AND COSTS

The implementation of IPM programs has resulted in significant benefits to all facets of society. Growers have benefited through:

a) improved pest control and stability in agricultural production; b) potential reductions in pest control costs; c) the delayed development of pesticide resistance, and d) reduced exposure to pesticides. Consumers have benefited through:
a) potential reduction of pesticide residues in food, and b) more stable prices. The agrochemical industry has benefited by the delayed development of pesticide resistance and the more effective and safe use of pesticides. Society, in general, has benefited through reduced toxic residues in the environment and a more stable agricultural production system (Newsom, 1975).

The costs of running IPM programs have varied from less than $1.00 to approximately $85.00/ha ($0.50 to $35.00/acre). The costs are dependent upon the intensity of pest monitoring required for the specific crop. Orchards, cotton and vegetables require more intensive monitoring and thus are more costly than IPM in field and forage crops. The costs of developing IPM systems has been borne by government-funded programs. However, the costs of running IPM programs has been borne solely by the grower, or shared between the grower and government. The latter is the preferred situation as significant benefits not only occur to the grower, but to society in general. In relation to the value of the crop and the benefits accrued from IPM, these costs are indeed acceptable.

IPM PESTICIDE APPLICATION

It is evident that IPM will, in the foreseeable future, rely to a major extent on pesticides to provide the high degree of control required in many crops. Certainly for the control of weeds in most crops, the only viable option is the use of herbicides and it is likely that herbicide use will continue to increase as more growers adopt reduced tillage practices. In IPM programs, pesticides must be applied in the most efficient manner possible with minimal contamination of nontarget areas. Thus, IPM research must include the improvement of pesticide application technology.

Many of the speakers at this symposium will address specifically this problem of increased efficacy of aerial application methods.

What major changes in the aerial application of pesticides can we foresee as a result of IPM? The changes in the foreseeable future will be relatively minor. We can expect the use of more diverse and improved aerial application equipment to deliver pesticides in the most efficient manner possible. In some situations, aerial application will be relied upon to provide the rapid response necessary for the optimum timing of pesticide applications. However, the changes will certainly not result in a revolution in the industry, rather an evolution as all parts of agricultural production are evolving to more efficient and sustainable agricultural production systems.

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Paper No. I-C

ECONOMIC AND ENERGY CONSIDERATIONS IN AERIAL APPLICATIONS

H.T.M. Colwell
Inputs and Technology Analysis Division
Regional Development Branch
Agriculture Canada
Ottawa, Ontario K1A 0C5

ABSTRACT

This paper provides an economic and energy overview of aerial applications in agriculture. The available information on the extent and types of applications of aircraft in agriculture is reviewed. Particular consideration is given to regional differences. The examination of energy considerations includes a comparison of quantities and types of energy required for aerial and ground spraying. The economic overview identifies both private and public cost factors associated with aerial and ground spraying.

INTRODUCTORY REMARKS

The symposium title "The Future Role of Aviation in Agriculture" raised many questions as to the conditions under which agricultural aviation would expand in the future. Some of these questions are noted in Figure 1 under the Energy and Economic consideration headings. One could also postulate other considerations, e.g., environmental, but these are outside my topic.

This paper is subdivided into 5 parts: Part 1 addresses use of aircraft in agriculture in the recent past followed by part 2 a review of potential applications in agriculture. The major components of the paper are Part 3 energy considerations and Part 4 economic considerations. Part 5 contains some concluding comments.

Figure 1: INCREASED USE OF AIRCRAFT IN CANADIAN AGRICULTURE

Energy Considerations

Will increased aviation use in agriculture:

1. conserve potentially scarce types of non-renewable resources by replacing then with more available fuels?
2. result in a net reduction in energy use per unit of food produced - will it increase energy productivity?
3. diversify the energy sources used by agriculture sufficiently to reduce the short-run impact of an energy supply disruption?

Economic Considerations

Will increased use of aviation in agriculture:

1. reduce the cost of producing a hectare of a specified crop?
2. reduce the cost or increase the profit from producing a tonne of product, e.g., wheat, by increasing the yield and/or quality so that the extra return to the farmer is greater than the extra cost of aerial applications?
3. increase the costs which must be paid by the public sector for externalities (e.g., environmental pollution) by less than the decrease in private costs - is there a net gain to Canada?
4. impact in a positive way on the attainment of national goals such as increased employment and regional development?

PART 1: USE OF AIRCRAFT IN AGRICULTURE

Literature searches of computerized data bases indicated that published quantitative data related to the use of aircraft in Canadian agriculture is extremely limited. However, a questionnaire survey of rural aircraft operators was undertaken in 1976 by Agriculture Canada and will form the basis of this section (King, G.J., 1978).

Approximately 1.0 million hectares of agricultural land were sprayed in 1976, 80 percent of which was located in the three Prairie Provinces (Table 1). The available data from earlier years suggest that the extent of aerial spraying activities more than doubled between 1971 and 1976. Some two-thirds of all agricultural land sprayed in 1976 was for control of weed and plant disease (Table 2). The second most important activity was insect control performed on 15 percent of the area subjected to aerial application. Other activities such as fertilizing, seeding, brush control and defoliation each accounted for less than 4 percent of the aerial activity.

Regional differences in relative importance existed. In the Prairie Provinces, weed and plant disease control, which was substantially more important than any other Prairie or Canadian activity, accounted for 57 percent of the total area actually treated. In Eastern Canada and British Columbia, however, insect control was of equal importance to weed and plant disease control (Table 2).

The relative importance of aerial spraying can be placed in perspective by recalling that in the Agricultural Census records for 1980 over 15 million hectares of land received weed and brush control treatment while 1.65 million hectares were treated for the control of insects and disease. Aerial applications in 1976, therefore, represented approximately 5 percent of the area treated in 1980.

Aircraft were used less frequently for a range of other agricultural activities which can be subdivided into three main categories viz livestock management, crop and land management, and farm and equipment management. The most frequently quoted activity was checking livestock, crops or land.

Approximately one-eighth of the 380 operators who reported involvement in agricultural activities in 1976 were licensed commercial operators. A recent estimate (Agriculture Aviation, 1983) of 200 aerial applicators in Canada indicates that the size of the industry has not changed substantially since 1976. Approximately one in four of the operators involved in 1976 in the use of aircraft for aerial applications of chemicals, fertilizer and seed were licensed commercial operators in 1976 (Table 3). The relative importance of commercial operators in aerial applications is evident from the 1976 data which indicates that the fifty commercial operators accounted for approximately sixty percent of the farmland and area covered while the 129 private operators were responsible for the remaining forty percent of activity (Tables 3 and 4). It is interesting to note, in view of the substantial capital cost and capacity of aircraft, that the level of utilization per operator in 1976 was very low. Private operators on average used their aircraft for agricultural purposes for only 66 hours during 1976. Commercial operators on the other hand indicated 280 hours of use on average (Table 5).

PART 2: POTENTIAL APPLICATIONS IN AGRICULTURE

I intend to touch only briefly on potential applications since these will be covered in detail by other papers. The existing set of applications has been summarized by Morley (1976) and as noted in Figure 2. The potential for increased use of aircraft in agriculture will depend primarily on their ability to undertake these existing applications in a manner which is more beneficial, e.g., in terms of economics, environmental aspects, or timeliness than existing methods. Unique characteristics of the aircraft such as their speed and their lack of a need to touch the ground while spraying are likely to be important, particularly on applications to land which has a topography, vegetation, or soil type which make it difficult for ground applications.

The aircraft may, therefore, have a role in extending the area where plant and animal protection agents can be profitably applied. The potential may be substantial with respect to current use. Crop dusting or spraying can be used as an example. Although there has been a substantial increase in the extent of use of sprays in agriculture, it is constructive to recall that only one-half of Canadian farms report dusting or spraying on their farms and that the total area sprayed and dusted accounts for only one-quarter of the total area of census farms (Table 6).

Figure 2: USES OF AIRCRAFT

A) Plant and Animal Protection
  i) Control of insects, e.g., aphids, army worms, biting flies, locusts, grasshoppers, etc.
  ii) Control of fungi, nematodes, vertebrate pests, etc.
  iii) Control of unwanted competitive plant growth such as weeds and brush
  iv) Biological control by release of insect predators and parasites, sterile insects, etc.

B) Plant Nutrition
Fertilizer application including trace nutrients

C) Seeding
Crops, grasslands and forests for food and fibre production as well as to provide some control of water and wind erosion. Nowadays often combined with fertilizer application.

D) Crop Harvesting Aids
  i) Controlled plant growth and maturation
  ii) Desiccation and defoliation

E) Photographic Surveys
  i) Crop loss assessment
  ii) Land use and changes in land use
  iii) Mapping and analysis, e.g. soil surveying, watershed studies, dam sites, irrigation, rangeland classification, snow and rain-falls, etc.
  iv) Verification of satellite imagery results

F) General
  i) Firefighting
  ii) Control of Disease vectors, e.g. malaria, encephalitis
  iii) Control of unwanted fish, aquatic plants as aids to fish production
  iv) Transportation - farm supplies, fencing, emergency feeding, etc.
  v) Pollination aids, either dispersal of pollens or insect pollinators
  vi) Herding animals
  vii) Selective logging of forests
  viii) Weather modification, rain making and storm prevention

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Source: Morley 1976

PART 3: ENERGY CONSIDERATIONS

This section discusses the three energy considerations identified in Figure 1. The emphasis is placed on isolating issues related to these considerations rather than arriving at concrete conclusions on each.

Consideration 1: Would increased use of aviation in agriculture conserve potentially scarce types of non-renewable resources by replacing them with more available fuels?

Increased use of aviation implies replacing some of the existing demand for diesel fuel by aviation fuel (if aerial treatments replaced ground treatments) or increasing the demand for aviation fuel (if aerial treatments are primarily used to extend the current geographical area to be sprayed).

Both aviation fuel and diesel are refined from crude oil. Aviation gasoline is classified as a light distillate while diesel fuel is a middle distillate. Diesel fuel is somewhat heavier than aviation gas. The National Energy Program document of 1980 indicates that generally the heavier the crude oil - and crude oil production is becoming heavier worldwide - the smaller the portion of light refined products becomes of total production. Therefore, over time, one would expect the yield of aviation gas per barrel of oil to decline compared to diesel. A barrel of crude oil, when refined, yields a substantially large proportion of diesel compared with aviation gas. In addition, the size of the market for aviation fuel is much smaller (approximately 30 percent) than the size of the diesel fuel market.

These factors suggest that increased use of aviation in agriculture would have a negative impact on this consideration. However, it is important to note that the demand for aviation fuel by agriculture is likely to be very small relative to the total demand for that fuel.

Consideration 2: Would increased use of aviation in agriculture result in a higher level of energy productivity in the production of agricultural commodities?

Energy productivity, which is defined for the purposes of this discussion as output per unit of energy input, can be improved by increasing output with the same quantity of energy inputs or by using a reduced quantity of energy to produce the existing level of output.

The information base available to address this consideration is very limited. Some recent work by Agriculture Canada (Timbers and Hocking, 1978) suggests that the energy consumption (as fuel) for aerial and ground spraying per hectare is likely to be similar. A literative review suggests that the available information on energy use by helicopters compared to ground rigs is insufficient to reach a conclusion.

Energy consumption per hectare could also be reduced if lower chemical application rates were used in aerial applications while maintaining the same level of weed and insect control. Again the evidence is incomplete. It is reported that pesticide dosages for aerial applications in Quebec are the same as for ground application (Theriault, 1981). Concerns in western Canada (Hay, 1981) about the portion of pesticide not reaching the target area, i.e., the drift problem and the need to improve uniformity of deposits, suggest that at present it may be necessary to use higher chemical application rates per hectare to obtain the same level of control as could be obtained with ground application. Thus, at present it is likely that aerial application uses somewhat more energy per hectare than ground application. A relevant question for investigation by research would seem to be, "Can this energy loss be reduced by research?".

This increase in energy quantities may well be counteracted if aerially applied treatments result in larger quantities of product available for sale. Intuitively, and based on the available empirical evidence, it would seem that there are a substantial number of farm production operations, e.g., seeding, fertilizing and spraying where saleable yields can be raised through timely application of treatments. The aircraft or helicopter would appear to have a substantial potential advantage over ground equipment with respect to timeliness of application.

In summary, it would seem that although increased use of aviation may not reduce the quantity of energy used per unit area or in aggregate terms, it may well be possible to increase energy productivity in these operations where timeliness of application is a critical factor.

Consideration 3: Would increased use of aviation in agriculture diversify the energy sources used by agriculture sufficiently to reduce the impact of a short-run energy supply disruption?

Longer-run energy concerns relate to the supply and price of nonrenewable energies. Diesel and aviation gas are both nonrenewable energies. One strategy which could be used to reduce the impact on the farmer's income and the nation's ability to feed its population in a short-term supply disruption is to diversify the types of energy mix used in farm applications.

In 1981, Canadian agriculture used 1,441 million litres of gasoline and 1,640 million litres of diesel as its major direct fuels. Smaller quantities of liquified petroleum gases, natural gas, heating oil and electricity were also consumed. The crop-based prairie farming system, in which most of the aerial applications occur, accounts for 69 percent of Canadian farm business expenditures on gasoline and diesel. Moreover, energy imputs to the Prairie farm system are dominated by diesel and gasoline use in mobile farm equipment, trucks and automobiles (Table 7).

The three farm operations most likely to be impacted upon by increased use of aerial activities are fertilizing, herbicide application and seeding. Analysis of data from the 1981 Farm Energy Use Survey indicates that approximately 200 million litres of fuel were used by Prairie grain farmers in these activities. Approximately 80 percent of that fuel would be diesel, with the remainder being gasoline.

Liquid fuel use by the agriculture sector is a major component of total liquid fuel consumption in the Prairie economy. Farm use accounted for 26.4 percent of all diesel fuel used in the three Prairie provinces during 1981. A comparable statistic for gasoline was 13.5 percent. The predominance of farm-based uses is most marked in Saskatchewan.

In light of the importance of gasoline and diesel supply for farm uses in the Prairies, any switching to aviation gas would reduce the dependance on the existing two fuels and help to diversify the energy sources available to farmers in short-run periods of supply shortage. However, the impact of such switching on the relative use of diesel and gasoline is likely to be quite limited. For example, if all the fertilizing and seeding were done by aerial application using aviation gas, it would reduce the farm use of diesel from 26 percent of the total in the Prairie economy by between one and two percent.

PART 4: ECONOMIC CONSIDERATIONS

The extent of future use of aircraft in agriculture is dependent on sets of decisions by farmers and by aircraft owners. A farmer has the option of using his own spray equipment, using a custom operator with a ground sprayer, using a custom aerial operator, or using a combination of these three possibilities. Similarly, the aerial spray operator must make decisions as to whether he will offer his aerial equipment exclusively for agricultural work or to non-agricultural work or whether he will undertake a mixture of agricultural and non-agricultural activities.

The basic economic consideration facing the farmer is which of these three options is least expensive when measured as cost per unit of ouput, e.g., cost of grain produced. If he runs his own sprayer, he will have some costs, e.g., principal and interest payments, insurance, etc. which are relatively fixed irrespective of the amount of use he makes of the sprayer. But the greater the use he makes of the sprayer, the lower will become the average fixed costs per unit of output (see Figure 3). Variable cost items, e.g., fuel, chemicals, lubrication and operator labour, measured as variable cost per unit of output tend to decline initially as use increases but then increase at higher levels of usage because of factors such as location of fields further away from the farmstead which increases fuel and time used for travel activities.

Thus, average total costs per unit of output tend to initially fall very rapidly, reach a minimum and subsequently increase.

The decision facing the farmer is generally "If I use a custom operator for my level of output, will the price per unit of output be higher than the average total costs if I have my own machine?". The important factor is cost per unit of output. For example, if Method A has costs of $4/seeded acre and we receive a yield of 1.00 tonne of wheat per seeded acre, while Method B has costs of $5/seeded acre and a yield of 1.30 tonnes per seeded acre, the cost per unit of output, i.e., $/tonne will be lower for the latter. Consequently, the question facing the potential aerial operator is whether he can keep his cost level, measured as average total costs, below a price which farmers will be prepared to pay to use aerial spraying as opposed to either custom ground or owned ground equipment. It is important to note in Figure 3 that the average total costs/unit of output diminish rapidly as use rises from a low level. This is important given the low levels of average utilization noted earlier in Table 5.

Information on custom charges in Alberta (Table 8) indicate that the charges for aerial application (not including spray materials) have been slightly higher in 1981 and 1982 than comparable rates for ground custom rates. The rates quoted for owned equipment in Table 9 are somewhat lower than 1983 custom rates but are based on substantial annual use levels.

In Ontario, quoted aerial custom rates for spraying operations appear to be competitive with custom rates for ground applications (Table 8).

In general, very few detailed economic analyses of ground vs aerial spraying have been presented in the literature. A study in Western Canada (N.R.C. 1969) found that the costs of aerial application were higher than the costs of ground application. Philpotts (1971) reports an analysis with respect to potatoes in New Brunswick based on a limited number of farms. The results indicated that the higher application costs associated with aerial application were more than exceeded by the value of the extra potato yield. Whilst the results of these analyses are only of limited relevance now, they do raise the need to consider the impact on output per unit area as well as the impact in costs. This may be particularly relevant to those situations where judicious use of aerial spraying will increase the level of production by more than the level of costs. Crops which require some critical operations to control disease are obvious examples. In addition, the intensification by use of aerial application of fertilizers, etc., of rolling land currently unsuited to ground application may be of importance and economically justified in various parts of Canada, even though the custom costs of aerial fertilization appear to be higher than for ground application (Table 10). The seeding of crops into standing crops, e.g., soybeans into wheat, is another possible aerial application which may be justifiable.

It is important, when evaluating economic aspects of the future role of aircraft in agriculture, to recall that problems such as spray drift may result in cost to other private individuals, e.g., farmers with adjacent fields who suffer spray damage or to society in general through higher levels of pollution from drift. Often this latter class of costs is difficult to justify but, as in the case of the spruce budworm control programs in Eastern Canada, may cause major concern to the general public.

The economic considerations which are of relevance to the person who wishes to use an aircraft for agricultural purposes revolve around approaches to increasing the amount of use made of the equipment, i.e., what are the ways and means of move along the downward sloping segment of the average total cost curve (Figure 3).

PART 5: CONCLUDING COMMENTS

The objective was to consider economic and energy considerations related to use of aircraft in agricultural activities.

One can only reach tentative conclusions because of the limited information available in both energy and economic aspects. However, it would appear that increased use of agricultural aviation is likely to be relatively neutral with respect to energy considerations.

There appear to be some opportunities such as operations which are time sensitive or operations which are needed on land which is not easily accessible or covered by ground based equipment. The key to achieving economically competitive costs for aerial and ground applications is through reducing the average fixed costs per hectare sprayed. This could be achieved by a combination of:

- spraying season extension;
- identification of large tracts of land suited to aerial spraying;
- alternative types of aircraft with reduced fixed costs;
- obtaining a mix of agricultural and other aerial uses which reduces the inter-year variability in demand for services;
- reducing the cost and distance of getting from take-off point to spraying area.

I would conclude by making three points about research priorities relevant to this area:

1. Successful research related to reduction of the average fixed costs/ha should produce economic benefits of some magnitude compared to work aimed at reducing variable cost/ha.
2. Successful research and development findings related to alleviating problems such as spray drift which are of concern to the public are likely to be important.
3. Research related to agricultural aviation is one of a larger set of possible research activities related to agriculture. What is the priority of agricultural aviation research compared to other areas such as energy conservation, biotechnology, and soil salinity? Although this wider set of considerations is outside the scope of this paper, they are of obvious interest to research decision makers.

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Table 1: Area Sprayed by Aircraft in Canada 1976 by Agricultural Acitivty (000 Hectare)

Agricultural Activity	Prairies	Eastern Canada and B.C.	Canada
Weed and Plant Disease Control	612	89	701
Insect Control	73	88	161
Fertilizing	6	32	38
Seeding	6	2	8
Brush Control and Defoliation	28	9	37
Undifferentiated	131	--	131
Total	856	220	1076

Source: King, G.J., 1978.

Table 2: Distribution of Area of Aerial Application in 1976 by Region and Activity

Agricultural Activity	Prairies	Eastern Canada and B.C.	Canada
		%	
Weed and Plant Disease Control	56.99	8.28	65.28
Insect Control	6.79	8.17	14.96
Fertilizing	0.53	2.94	3.47
Seeding	0.51	0.14	0.65
Brush Control and Defoliation	2.63	0.81	3.44
Undifferentiated	12.19	-	12.19
Total	79.64	20.34	100.00

Source: King, G.J., 1978.

Table 3: Number of Operators Involved in Agricultural Aviation 1976, by Activity

	Aerial Application[1]	Any Agricultural Activity
Commercial	50	53
Private	129	327
Total	179	380

Source: King, G.J.,

[1] Aerial applications include weed and plant disease control, fertilizing, seeding, brush control and defoliation

Table 4: Relative Importance of Commercial and Private Aviators in Agricultural Activity, 1976

	Aerial Application[1]	Any Agricultural Activity
Commercial:		
% of Area	61	N/A
% of Flying Hours	60	41
Private:		
% of Area	39	N/A
% of Flying Hours	40	59

Source: King, G.J., 1978

[1] Aerial applications include weed and plant disease control, fertilizing, seeding, brush control and defoliation.

Table 5: Estimated Average Flying Hours Per Operator For All Agricultural Activities, 1976 (Hours[1])

	Aerial Application[1]	Any Agricultural Activity
Commercial:	240	280
Private:	63	66

Source: King, G.J., 1978

[1] Calculated as the:

$$\frac{\text{total number of hours during 1976 for this activity}}{\text{number of operators involved in this activity}}$$

Table 6. The Extent of Crop Dusting and Spraying in Canada

	1971	1981
Total number of census farms	366,128	318,361
Number of farms on which dusting or spraying occurred	164,398	167,712
Percentage of Census farms on which dusting or spraying occurred	44.9	52.7
Total area of census farms (hectare)	68,662,445	65,888,916
Area dusted or Sprayed (hectare)	8,874,607	16,872,549
Percentage of census farm area on which dusting or spraying occurred	13.1	25.6

Source: Statistics Canada - Census of Agriculture
1981 and 1971 Cat. 96-901

Table 7: Gasoline and Diesel Consumption 1981 - Prairie Provinces (millions of litres per annum)

	Manitoba	Saskatchewan	Alberta	Prairies
Gasoline				
Total Use, All Sectors[1]	1,542.5	2,000.3	5,081.4	8,624.2
Farm Use[2]	191.8	488.5	485.4	1,167.7
% of Total Use	12.4	24.4	9.6	13.5
Farm Business - Total	167.4	425.4	424.5	1,017.3
trucks and autos %	64	67	68	-
mobile farm machinery %	35	32	31	-
other %	1	1	1	-
Farm Business - Grain and Oilseed Production	125.1	374.9	326.5	826.5
Diesel				
Total Use, All Sectors[1]	752.6	1,041.4	2,803.3	4,597.3
Farm Use[2]	212.2	554.1	448.5	1,214.8
% of Total Use	28.2	53.2	16.0	26.4
Farm Business - Total	210.1	548.8	446.1	1,205.0
trucks and autos %	3	2	4	-
mobile farm machinery %	97	97	96	-
Farm Business - Grain and Oilseed Production	156.5	510.0	367.9	1,034.4

Sources: Adapted from Canadian Resourcecon 1983. Oil Conservation on Prairie Farms. A Study conducted for the Development Policy Directorate, Regional Development Branch, Agriculture Canada.

Notes:

1. Total Use: Statistics Canada, Cat. No. 57-003, "Quarterly Report on Energy Supply-Demand in Canada". Fourth Quarter, 1981.

2. Farm Use: Statistics Canada, Cat. No. 21-519, "Farm Energy Use Survey" 1981.

Table 8: Cost Comparison of Ground and Aerial Application of Herbicide Sprays[1] $/Hectare

Year		Ground Custom Service	Aerial Custom Service
Alberta			
1978		1.85 - 5.00	4.10 - 5.50
1979		1.75 - 5.00	3.95 - 6.20
1980		2.50 - 6.20	4.69 - 6.20
1981		5.00 - 6.20	6.20 - 9.90
1982		4.32 - 6.80	6.20 - 9.25
1983		5.00 - 7.40	6.80 - 10.00
Ontario			
1982	Herbicides	- -	11.10 - 18.50
	Insecticides	7.40 - 24.75	11.10 - 24.75
	Fungicides	- -	11.10 - 18.50
1983	Herbicides	- -	11.10 - 17.25
	Insecticides	9.90 - 19.80	8.65 - 17.25
	Fungicides	- -	8.65 - 17.25

[1] Costs including equipment and operator labour but excluding spray materials cost

Sources: Alberta Agriculture Custom Rates Annual Summary - various years.
Alberta Agriculture Farm Machinery Costs as a Guide to Custom Rates - various years.
Ontario Ministry of Agriculture and Food. A Survey of Custom Farmwork Rates Charged in Ontario - various years.

Table 9: Assumptions Related to Costs of Owning Sprayers 1983

Type of Equipment and boom Length	Total Cost/Hour[1] $	Annual Use Hours	Operating Rate Acre/Hour	Area Sprayed Acre	Total Cost/Acre
Trailer Sprayer					
250 gallon 55'	30.50	50	20.00	1,000	1.52
400 gallon 65'	33.25	50	25.00	1,250	1.33
Self-propelled Sprayer					
130 gallon 54'	39.24	100	40.00	4,000	0.98
1,000 gallon 54' float	178.28	100	85.00	8,500	2.10
320 gallon 45' + 3/4 ton 4 × 4	41.26	100	35.00	3,500	1.18

[1] Assumes $7/hr. for labour and no profit margin

Source: Alberta Agriculture 1983. Farm Machinery Costs as a Guide to Custom Rates, Spring 1983.

Table 10: Cost Comparison of Ground and Aerial Custom Application of Fertilizer[1] $/Hectare

Year and Province	Ground	Aerial
Alberta		
1978	3.10 - 4.30	10.00
1979	2.50 - 5.00	3.70 - 10.00
1981	5.00 - 6.20	6.20 - 14.80
1982	3.70 - 6.80	6.80 - 14.80
Ontario		
1982	12.35 - 21.00	14.80 - 20.65
1983	13.60 - 22.25	14.80 - 34.60

Note:

[1] Costs include equipment and operator labour but exclude material costs

Source: Alberta Agriculture 1983. Farm Machinery Costs as a Guide to Custom Rates. Spring 1983.

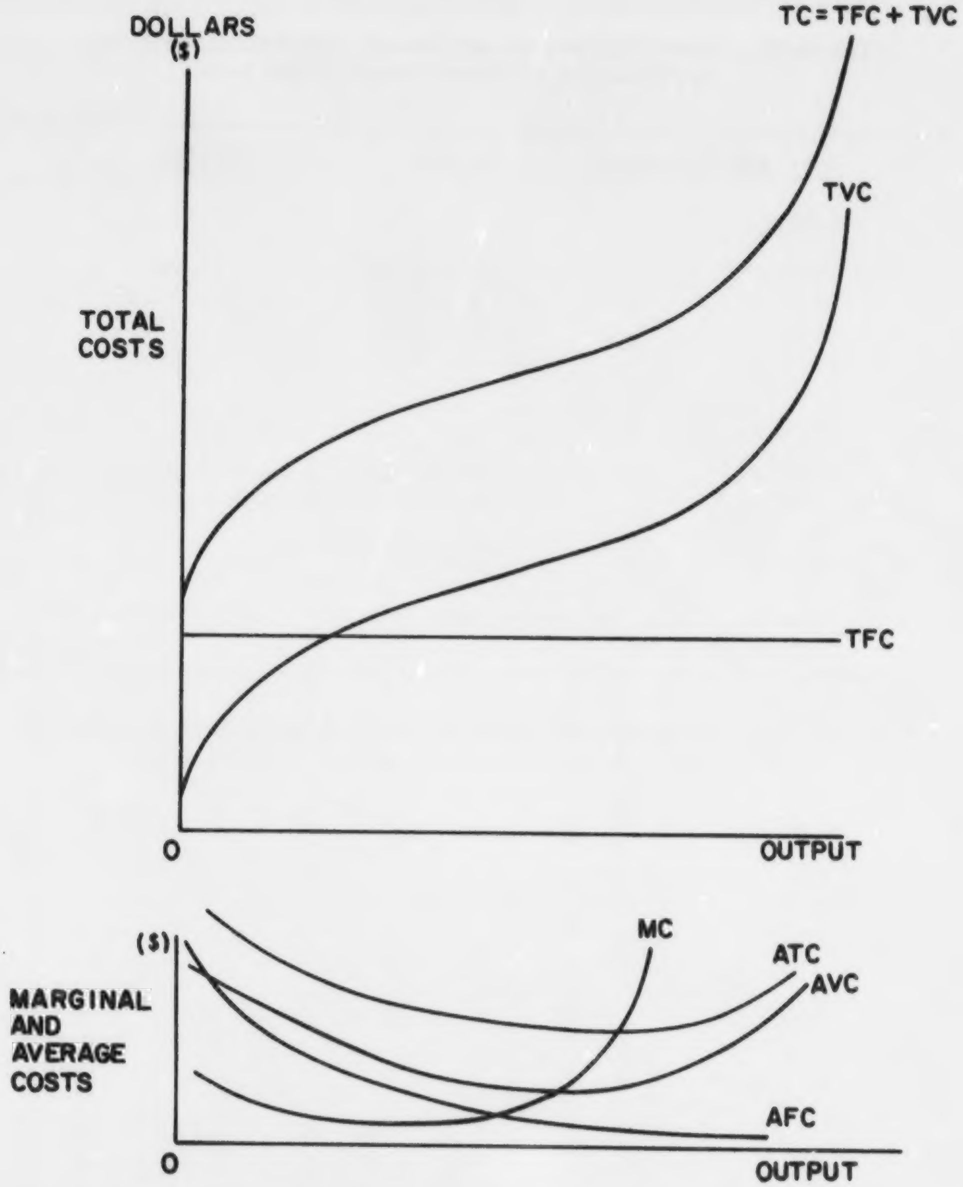

Figure 3. The Seven Cost Functions.
TC Total Costs
TVC Total Variable Costs
ATC Average Total Costs per Unit of Output
AVC Average Variable Costs per Unit of Output
MC Marginal Costs
AFC Average Fixed Costs

Paper No. II-A

ENVIRONMENTAL CONCERNS

George G. Shaw
Canadian Wildlife Service
9942 - 108 Street
Edmonton, Alberta T5K 2J5

and

D.K. Smith, P.J. Sheehan and P. Mineau
National Wildlife Research Centre
Environment Canada
Ottawa, Ontario K1A 0E7

ABSTRACT

Off target drift of agricultural chemicals remains the major environmental concern in aerial application despite more than two decades of research directed toward minimizing such drift. This concern and a few minor environmental concerns associated with aerial application were indicated in responses from farm organizations, conservation groups and three levels of government.

The pesticide drift into prairie wetlands intimately associated with cropland is a major concern of government agencies responsible for wildlife which utilize the wetlands.

INTRODUCTION

The anticipated expansion of aerial application of pesticides poses some unique environmental problems for the prairie provinces. Simply stated, the principal concern with this method of application is the increased likelihood of off-target contamination given the close proximity of vulnerable non-target areas to sites of aerial application. Areas susceptible to either pesticide drift or direct overspray include wetlands, hedgerows and shelter belts which are often the only viable remaining fish and wildlife habitat in intensively cultivated areas. A different but related concern is the loss of upland wildlife habitat that results from the intentional aerial application of herbicides for brush control.

In general, there is a growing awareness of these problems among provincial and federal agencies responsible for protection of the environment and the development of agriculture. Full implications of the aerial application of pesticides are, however, not appreciated by all sectors outside of government. Out of the thirty-one conservation groups canvassed for this paper, only two (the Canadian Nature Federation and the Canadian Wildlife Federation) responded. These two organizations either opposed or would like to see aerial applications of pesticides restricted because of risks to wildlife. It is also difficult to know where the prairie farming community and the general public stand on the issue. Some components of the farm community and of the general public have expressed their concern with environmental degradation resulting from the use of pesticides (see National Farmers Union, 1983 and Department of Environment, 1982, 1983). Neither has specifically referred to aerial applications of agricultural chemicals. Better understanding of some of the environmental risks associated with pesticides applied by aircraft and of the potential impact of this practice on prairie waterfowl and upland game birds are the focus of this paper.

The area known as the prairie pothole region and associated grasslands provides the breeding habitat for up to 50% of the total North American duck population (Patterson, 1978). This habitat is composed of some 5 to 6 million potholes (Gollop, 1965) with densities ranging from $12/km^2$ for the whole prairie (Smith et al. 1964) to a maximum of $46/km^2$ in portions of southeastern Saskatchewan (Lynch et al. 1983). Aerial photographs reveal that these permanent and semipermanent potholes are intimately associated with croplands. The most numerous and waterfowl productive potholes are in the 404 to 4047 m^2 size range, (Cooch, 1969; Smith 1971). Even in areas where slough densities are below the prairie average, the distance between edges of adjacent sloughs can be quite small. For example, in Alberta section 29, township 47, range 9 west of the 4th meridian contains some 22 permanent and semipermanent sloughs (8.5 potholes/km^2). The average distance between adjacent potholes, all of which are less than 4097 m^2, is 185 ± 77 m (error represents one standard deviation). Aerial application within such a region would certainly result in drift contamination and probably also in direct overspray of many sloughs. Further contamination of this vital habitat is serious particularly for waterfowl threatened by the physical destruction of nesting and foraging habitat as a result of agricultural practices (Brace and Caswell, 1983).

Pesticide Use

Assessment of the environmental impact of pesticide use in the prairies requires information about the type, quantity and the timing as well as the method of application (i.e. ground rig or aerial), and the proximity of the target areas to wildlife habitat. In the prairies over 12 million ha are annually sprayed for weed and brush control and approximately 1 million ha are sprayed for insect and disease control (Statistics Canada, 1982). Herbicide use has generally increased over the years (Daciw, 1972-81) whereas insecticide use in the prairies usually follows pest outbreaks and is therefore difficult to quantify. Contributing to the difficulty is the fact that at present no agency (government or private) collects or compiles comprehensive data on the annual use of these compounds in the prairies. It has been estimated that the total area sprayed with insecticides is somewhere between 500,000 to 1,700,000 ha per year (Smith et al. 1984).

The principal herbicides used in the control of the broad leaf weed include compounds such as MCPA, 2,4-D, dicamba and bromoxynil whereas wild oats and other grassy weeds are primarily controlled by triallate, trifluralin and barban (Thomas 1978, 1980). Insecticides frequently used in the prairies for control of pests like grasshoppers, flea beetles and bertha army worm are carbaryl, carbofuran, chlorpyrifos, dimethoate and malathion, all of which can be applied by air.

Pesticides are applied aerially by either commercial operators, licensed within the provinces, or directly by farmers who can obtain a waiver from the Canadian Transport Commission that permits them to make applications within 25 miles of their own farm. This latter group is probably responsible for most of the aerial applications. The contribution of flying farmers to spraying is difficult to estimate since none of the provincial governments monitor this practice. Although some of the provinces have legislation requiring commercial applicators to supply records of all applications, only Alberta has summarized these data. It is estimated that collected data represents only 50 to 65% of the activities of the licensed applicators in the province (N. Wandler, Alberta, Environment pers. comm.). According to this Alberta source the top six herbicides applied aerially in 1981 were 2,4-D, MCPA, trifluralin, triallate, bromoxynil and picloram with difenzoquat displacing bromoxynil from the list in 1982. The major insecticides applied aerially were temephos, carbofuran and chlorpyrifos in 1981 and chlorpyrifos, malathion and dimethoate in 1982.

Maybank et al. (1978) estimated that 5 to 10% of herbicides and, depending on the insect pest involved, most insecticides may be applied by aircraft. Using an upper limit of 10% and 60% for aerial application of herbicides and insecticides respectively and the overlap of productive waterfowl habitat with agricultural land of approximately 60% (Smith et al. 1984) one can estimate the probability of aerial application of chemicals within this habitat. Given the above assumptions, the current annual overlap of aerial application of pesticides with productive waterfowl habitat is <5%. If the use of aircraft delivery were to increase to levels comparable to that found in more intensively cultivated areas such as California, approximately 80% of pesticides would be applied by aircraft in the prairies (C. Tuomela, California Agricultural Aircraft Association pers. comm.). For herbicides alone, this would mean an increase to 13% in overlap between sprayed crops and productive waterfowl habitat. This calculation also assumes no growth in annual herbicide use, which is not very realistic considering the present trend to no-till farming. Given that on an annual basis 19% of productive waterfowl habitat may be within areas of pesticide applications (principally herbicides, Smith et al. 1984), the cumulative impact of direct habitat contamination via aerial spray in conjunction with drift from ground rig systems, may have already reduced the viability of this critical waterfowl habitat.

Drift From Aerial Application

At present, there are no data available that specifically address the drift and overspray problems associated with aerial application of pesticides in crop areas containing prairie sloughs. The information that is available suggests that slough contamination is highly probable for certain regions of the prairie. Drift from aerial application represents 20-35% of the volume applied by aircraft as compared to 1-8% of the volume applied by ground rig (Maybank et al. 1978). Weather conditions and several other factors such as nozzle type and mounting position on the aircraft, type of aircraft, its speed and altitude and chemical formulation all affect the extent of off-target drift of chemicals. These factors have already been reviewed: Yates et al. (1966) and Kaupke and Yates (1966), Yates and Akesson (1973), Wilce et al. (1974), Maybank et al. (1974), Yates et al. (1977) and Ware et al. (1969a, 1970a,b, 1972 and 1974). See also the more recent bibliography by McKinley and Ford (1981).

Even with good equipment and favorable weather conditions, several authors have reported measurable drift several hundred meters downwind of aerial applications. Argauer et al. (1968) recorded detectable levels of malathion and azinphos-methyl up to 600 m downwind of single swath aerial applications made in 6.5 to 10 km/h winds at 9.1 m above the ground. In this study the mortality of adult fruit flies (Drosophila and melanogaster) exposed to residues collected at distances from 300 to 780 m downwind were variable, ranging from 0 to 92%. Aerial application of methoxychlor (approximately 1.68 kg/ha) in 4.8-8.1 km/h winds caused 0.14 ppm residue 804 m downwind as compared to 111 ppm on samples taken within the target area (Ware et al. 1969b).

Drift potential is higher with insecticide applications than with herbicide applications because the average size of droplets emitted from nozzles used with insecticides is smaller. Wilce et al. (1974) suggested that herbicide spray drift (i.e., 2,4-D) with only 0.1 percent of droplets under 100 μm in diameter could cause damage to susceptible crops at distances of two or more kilometers from the aerially treated field.

Under weather conditions conducive to minimal drift, Yates et al. (1977) calculated that 1.3 to 2.8% of initial aerial application volume (approximately 2.27 kg ai/ha) was deposited between 100 and 400 m downwind when DDT was applied with rotary atomizer nozzles. The highest concentrations of the chemical on alfalfa ranged from 2.12 ppm at 100 m to 0.12 ppm at 400 m downwind compared to 42 ppm within the target area.

Under conditions normally experienced in the Canadian prairies, Maybank et al. (1978) estimated the total drift (averaged to a height of 4 m) at 500 m downwind from a 2.59 km^2 area of cropland aerially sprayed with 2,4-D Amine to be 330 mg/m^2. Only 20 mg of 2,4-D/m^2 deposition is considered sufficient for weed control. It can therefore be assumed that sensitive off-target plant species may also be damaged. Drift of endrin and permethrin aerially applied to crops for cutworm control was sufficient to kill all aquatic invertebrates (i.e. Daphnia magna) exposed in beakers of water at all distances up to 361 m downwind within 24 hours (Schladweiler and Weigand, 1983).

These examples strongly suggest that even under favourable conditions (weather, adequate operator training and equipment) off-target spray drift from aerial applications may be appreciable several hundred meters downwind. Given the densities of sloughs in certain regions of the prairie, drift and direct over-spray contamination of waterfowl habitat would appear inevitable with aerial application of pesticides.

Potential Impacts on Wildlife

Available evidence indicates that both direct mortality and indirect effects on population success are associated with pesticide contamination of waterfowl habitat. Indirect effects are the result of induced changes in breeding, nesting and foraging habitat as well as the result of elimination of essential plant and invertebrate food during critical periods of hen and duckling dependency.

Direct Toxicity

Several cases of insecticide poisoning of waterfowl species have been reported for compounds registered in Canada for aerial application. Hill and Fleming (1982) examined a case of Canada goose (Branta canadensis) mortality on or adjacent to a field that had been aerially sprayed with diazinon less than 24 hours prior to the kill. They also present a case of American Widgeon (Anas americana) mortality due to carbofuran. A number of similar cases have been reported and are currently being investigated by the United States Fish and Wildlife Service at the Patuxent Wildlife Research Center.

Destruction of Breeding Habitat, Cover and Food Supply

Herbicide drift into non-target areas such as slough margins and hedgerows can cause changes in vegetation which subsequently affect the nesting success, predator avoidance and foraging of game bird species. Waterfowl preference for specific habitat characteristics has been documented. For example, dabbler broods require abundant undisturbed nesting cover. Dywer (1970) reported twice the number of dabbler broods on potholes in non-agricultural areas, that provided more cover, than were observed on sloughs in agricultural areas. Vegetative changes induced by the herbicide 2,4-D altered the number and distribution of nesting ducks at an Alberta study site. Numbers of nesting ducks declined due to significant reductions in broad-leaf plants providing preferable nesting habitat along slough margins (Dwernychuk and Boag, 1973).

Aerial application of herbicides for brush control will also impinge on the cover and feeding habitat of prairie upland game birds such as the grey partridge (Perdix perdix L.), due to their dependence on invertebrate prey in hedgerows and other edge habitat during the first weeks after hatching (Schladweiler and Weigand, 1983).

Sugden (1973) detailed the composition of duckling diets as a function of age for four species Pintail (A. acuta), Gadwall (A. stepera), American Widgeon and Lesser Scaup (Aythya affinis)). When integrated over the entire prefledging period, plant food made up the dominant portion of duckling diet for three of the four species. Widgeon and Gadwall consumed an average of 90% plant food while Pintails consumed 60% aquatic insects and 30% submergent plants. The Lesser Scaup feed almost exclusively on aquatic invertebrates (approximately 95%). Submergent plant species important to duckling diet (40-60% by dry weight for American Widgeons and Gadwalls) such as Potamogeton pusillus and Lemna minor, can be completely eliminated by paraquat, diaquat, simazine, 2,4-D, and other herbicides (e.g. Way et al. 1971, Simpson and Pimental, 1972, Newbold et al. 1974). Regrowth of aquatic vegetation is slow (not within a single growth season) and benthic algae and Chara, plant species not contributing to duckling diet, become dominant after herbicide exposure (Crawford, 1980).

Regardless of their eventual feeding habits, all ducklings are strictly dependent upon aquatic invertebrates for about the first ten days of life. Important dietary items for young ducklings are diptera larvae, amphipods and cladocerans (Sudgen, 1973), taxa shown to be sensitive to some of the insecticides.

Female ducks require additional protein and calcium during the egg laying period, which they obtain by consuming large quantities of aquatic invertebrates. Swanson et al. (1979) found the proportion of invertebrates in the diet of laying ducks to range from 99% for blue-winged Teals (Anas discors) and Shovelers (A. clypeata) to 77%, 72% and 70% for Pintails, Gadwalls and Mallards (A. platyrhynchos) respectively. Gastropods, chironomid larva and various crustaceans were the principal food items selected by the females in this study. Krapu (1979) experimentally demonstrated that elimination of animal (invertebrate) protein from the diets of laying ducks had adverse effects on both clutch size and duckling survival.

Field studies in pond systems with aerially sprayed insecticides such as chlorpyrifos (Hurlbert et al. 1970, Macek et al. 1972), malathion (Kennedy and Walsh, 1970), carbaryl

(Gibbs et al. 1984) and cypermethrin (Crossland, 1982) have demonstrated immediate, and long lasting, impacts on aquatic invertebrate populations. As spray periods can overlap with duckling hatching and brooding, the Canadian Wildlife Service, National Wildlife Research Centre (NWRC) has undertaken an ecological risk analysis of insecticides widely used in Canadian prairies to evaluate the relative potential for population reductions of key invertebrate waterfowl prey (Smith et al. 1984).

The risk analysis uses the National Research Council computer model (NRCC, 1981) to predict the relative persistence of the insecticides in a standard well-mixed pond ecosystem and then compares predicted persistence parameters with the integrated median lethal toxicity value (LC_{50} × time) for standard invertebrate test species such as Daphnia magna and Gammarus lacustris.

For compounds with available physico-chemical and toxicity data, initial assessments assumed direct over-spray at the recommended application rates for cereal grain crops. The risk analysis assumes that insecticide impacts on aquatic invertebrate communities can be represented by data from short-term acute laboratory toxicity tests. The concentration required to kill 50 percent of the test population (LC_{50}) multiplied by the duration of exposure (t, days) represents an estimate of the integrated median lethal exposure and can be compared with predicted concentration in pond water to estimate the risk to invertebrate populations. The higher the calculated relative risk value, the greater the potential for castastrophic mortality in exposed slough invertebrate communities.

Persistence predictions are based on calculated estimates of insecticide transfer from water to the suspended solids and benthic sediment via diffusion processes, loss to the atmosphere through volatilization, and removal through hydrolytic and photolytic degradation reactions. Because of a lack of data and modeling simplicity, biodegradation of the insecticides is assumed to be negligible. Therefore, predicted retention in water and sediment is maximized providing a "worst case" estimate of persistence in the pond ecosystem. Persistence model simulations can calculate transfer and loss coefficients for insecticides under various temperature and pH conditions representative of seasonal and regional differences in prairie sloughs.

Preliminary results indicate that azinphos-methyl, chloropyrifos, cypermethrin, fenvalerate, malathion and methoxychlor present a relatively high acute risk to invertebrate survival (Table 1). Carbaryl presents a moderate acute risk, whereas diazinon and dimethoate present a negligible risk. Although no toxicity data for amphipods exposed to deltamethrin are available, application of the model to other aquatic crustaceans suggests that it might be included into the high risk category (index value 767 for the lobster Hommarus americanus). The Toxic Chemicals Section (NWRC) is currently refining the risk assessment model and expanding its study of waterfowl habitat destruction resulting from slough and slough margin contamination by both aerial and ground application of herbicides and insecticides.

SUMMARY

Aerial application of agricultural pesticides may result in environmental damage in many regions of the prairies. Increased pesticide drift and direct over-spray affects patches of wildlife habitat located within close proximity to spray areas. As aircraft use for pesticide application is increasing, the need to resolve the questions of pesticide induced changes in wildlife habitat is urgent and corrective measures are essential. Further studies of this subject should concentrate on assessing: 1) extent of aerial drift under conditions experienced in the prairies; 2) feasibility of establishing buffer zones in proximity of sensivite habitats; 3) pesticide use patterns including identification of the actives and their method of application. Concurrently, further study of the impacts of both aerially and ground applied pesticides on wildlife habitat structure and components of food webs in prairie wetlands must be undertaken. Until the above information is available and assessed, aerial application of pesticides should be minimized and restricted for toxic compounds such as synthetic pyrethroids until their impact is properly evaluated.

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Table 1: Median lethal toxicity and relative risk indices for Gammarus lacustris exposed to selected insecticides.

Insecticide	48 h LC_{50} $\mu g\ \ell^{-1}$	Relative Risk Index*
azinphos methyl	0.30	446
carbaryl	22	11
chlorpyrifos	0.4	606
cypermethrin	0.1^{α}	278
diazinon	500	1
dimethoate	400	1
fenvalerate	0.07^{β}	467
malathion	1.8	141
methoxychlor	1.3	240

*Relative risk index =

$$\frac{\text{Application rate} \times \dfrac{1}{\sum \text{first order rate constants for removal and transfer}}}{\text{Volume of mixing zone X integrated median lethal exposure}}$$

$^{\alpha}$24 h LC_{50} for Gammarus pulex

$^{\beta}$Gammarus pseudolimnaeus was test species

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Health and Safety Concerns Relating to Aerial Application of Pesticides

C.A. Franklin and N.I. Muir
Environmental Health Directorate
Department of National Health and Welfare
Ottawa, Ontario K1A 0L2

ABSTRACT

The assessment of potential health hazards resulting from the use of pesticides requires knowledge of both the toxicity of the product and the amount to which the population is exposed. The toxicity of the product is determined through extensive testing on a variety of species of animals and these data are used to predict the potential toxic effects in man and to estimate the levels at which these effects may occur. The requirements for toxicity testing have changed over the years, and the current requirements as well as suggestions for future directions are presented. In order to determine whether a product can be used safely, it is essential to know what the exposure to the product is. A number of studies have been conducted to determine exposure levels to people involved in the aerial application of pesticides and to estimate what the exposure would be to bystanders. The amount of pesticide exposure depends on a number of parameters including the type of formulation and the equipment used as well as personal habits of the applicator. The bystander exposure is also influenced by many factors which are discussed.

A survey of the licensing requirements for aerial application of all provinces is presented. There appears to be a tendency towards aerial application involving increasing numbers of farmers with the capability to do their own aerial application. There is

also a tendency for urban encroachment on rural lands which occasionally gives rise to conflict over the use of pesticides. The adequacy of existing regulations for aerial application to protect the user and the bystander will be discussed.

INTRODUCTION

The enormous increase in the use of pesticides since the 1940's has not been without controversy. The advocates claim that pesticide usage is an integral component in providing an adequate food supply and protecting human health. The opponents claim that severe and frequently irreversible damage is being done to the environment and that human health is also affected. Nowhere have these claims been as strong as in the aerial application of pesticides, particularly in the forestry setting.

There are obvious truths on both sides of the issue. There are data to support the economic benefits of increased yields derived from the use of pesticides as discussed by McEwen and Stephenson (1979). The human health benefits have also been great. The impact of DDT in malaria control has had far reaching ramifications on major segments of the world population.

However, pesticides are biologically toxic chemicals and are unfortunately not uniquely specific to the target. It is therefore essential that the potential risks involved with usage of a pesticide are carefully assessed and an informed decision made regarding the suitability of the pesticide for registration.

COMPONENTS OF RISK ASSESSMENT

Safety evaluation or risk assessment has been described as the characterization of the potential adverse health effects of human exposure to environmental hazards (Stallones, 1983) (Table 1). There are numerous and divergent definitions of risk, but the concepts that all definitions seem to embody are those of hazard and probability. There are a number of components to risk assessment which include hazard identification, risk estimation which would encompass dose-response assessment (species and low-dose extra- polation), exposure estimation and risk characterization (Table 2). Another aspect is risk management in which alternative regulatory strategies are considered and a course of action selected. The risk assessment process for pesticides in Canada is embodied in the Pest Control Products Act which is a federal act administered by Agriculture Canada.

HAZARD IDENTIFICATION AND DOSE-RESPONSE

Conventional methods of risk assessment utilize animal bioassay data as a means of identifying the specific hazards of a pesticide and enabling dose-response assessments to be made. The spectrum of toxicity tests conducted to support a submission for registration has evolved to the current standards which are outlined in Tables 3, 4, and 5. It should be emphasized that the registrant can be asked to provide other studies if deemed necessary to address particular problems. These studies are conducted with a variety of animal species dosed for varying periods of time via dermal, inhalation and oral routes of exposure. Through these tests, the target organ(s) can be identified as well as the most toxic route of exposure. The selection of doses is critical and a properly conducted toxicity study should include at least one dose that is sufficiently high to elicit a toxic response and one at which no effects are observed. The elucidation of the dose-response relationship is an important aspect of risk assessment.

Much more emphasis is being placed on understanding the mechanism of action of the pesticide particularly with respect to carcinogenesis, and this will undoubtedly enable further refinements in the quantitative aspects of risk assessment in the future.

EXPOSURE ASSESSMENT IN HUMANS

The estimation of exposure is a major component of risk assessment, and enables a perspective to be put on the toxicity data. It is apparent that a larger exposure could be tolerated to a less toxic chemical while still maintaining an acceptable margin of safety for use. One of the challenges in assessing risk to workers involved in a spray operation as well as to bystanders has been to develop accurate estimates of exposure. A bystander is defined as someone not directly involved in the spray operation but inadvertently exposed as a result of the application.

The aerial application of pesticides is an operation in which both the spray equipment and spray cloud are highly visible. There seems to be a perception that aerial application leads to high exposure, and this has been a hotly debated issue particularly with respect to the aerial application of pesticides for forestry.

Bystander Exposure

Bystanders to an aerial application are exposed primarily to off-target drift and over the years considerable effort has been directed to quantify drift from treated areas (Ware, 1969, Lee, 1976). The quantity of spray that reaches the target and the off-target drift depend on a number of factors including: amount of material sprayed; physicochemical properties of pesticide and final spray; particle size distribution; release height above target crop; wind speed and atmospheric turbulence. The particle size distribution of the spray is probably the most important factor contributing to off-target drift (Lewis, 1976). Spray droplets of less than 30 μm VMD have been shown to drift great distances. Aerosols of 2 μm VMD have been shown to drift as much as 34 km in a 3 km/h wind while falling only 3 m. However, vaporization of pesticide compounds during and after spray operations may be an important mechanism for entry into the atmosphere. Evaporation of liquid aerosol droplets as they fall through the air can release substantial quantities of the pesticides contained therein as vapors or as very small particles. Much research has been directed to the minimization of drift.

Utilizing relevant published information, use scenarios in which operating parameters were kept relatively constant were developed to estimate "theoretical worst case" bystander exposure (Houghton, 1978, Franklin et al. 1981). This was further refined when in 1979, the New Brunswick Task Force on Insecticide Drift for Forestry Spray Programs sponsored studies in which a computer model was developed to more precisely estimate the airborne concentrations of aminocarb and fenitrothion which were used in the New Brunswick spray program (Crabbe and Reid, 1980, Reid and Crabbe 1980). Field data were gathered (Crabbe et al. 1980a and b) and partial model validation was presented by Crabbe and Reid (1980).

For an application rate of 70 g ai$\cdot$ha^{-1} of aminocarb, the total exposure for a bystander in the spray swath as estimated by the preliminary "theoretical worst case" model was 40 μg$\cdot$kg-BW^{-1} compared to 7 μg$\cdot$kg-BW^{-1} from the computer derived model (NRCC, 1982). In both cases almost all of the exposure was dermal. In the computer model, the dermal route was predominant at the spray line and at the higher wind speed at distances of 400 m and 800 m (Table 6). The predominance of the oral route at 400 m and 800 m at lower windspeeds in the aminocarb application is a reflection of the lower terminal velocity of the smaller droplets. The computer model was able to consider many more factors than were feasible in the "theoretical worst case" model such as changing droplet size, terminal droplet velocity, solvent effects, shape of the target and it was also able to account for the wind effects. It is interesting to see that the crude preliminary model did overestimate exposure as was hoped for prudency sake but that the values were not unrealistic. It was also shown that exposure at 400 and 800 m from the spray line were essentially negligible (Table 6). In the models it has been presumed that all of the pesticide impinging on the skin would be absorbed. This would be a "worst case" estimate since it has been shown that pesticides are not all absorbed and in fact there is considerable variation in the penetration of pesticides ranging from approximately 5% for 2,4-D acid to levels in the 70-80% for some carbamates (Feldman and Maibach, 1974).

The computer model was used again, with the necessary modifications in parameters due to the differences in operations, to estimate bystander exposure following aerial application of 2,4-D in both an agricultural and a forestry situation (NRCC 1983). The data from these 2,4-D models are summarized in Table 6. In both of the 2,4-D uses, the primary route of exposure was dermal regardless of windspeed or distance from the sprayline. Despite the major differences in operational aspects of these applications there appears to be no major difference in exposure in the two types of forestry applications. The much lower exposure in the prairie use scenario is likely due to the much larger droplet size from the D6-46 nozzle which is used compared with the Teejet spray nozzle which was used for both types of forestry application.

It should be emphasized that it is unlikely that the extremely low exposures to bystanders in any of these estimates would be toxicologically significant regardless of route of exposure.

Validation of Bystander Exposure Model

Draper et al. (1981) attempted to quantify bystander exposure by extrapolating the concentration of parathion on plant surfaces in or near sprayed fields. They found 10% of the material sprayed at 50 m from the edge of the spray block. Using this figure and the rate of application, the exposure of a bystander with 15% of his skin exposed was modelled. This resulted in a theoretical dermal exposure for a bystander 50 m from the spray block of 12 $\mu g \cdot kg\text{-}BW^{-1}$ based on a rate of application of 280 $g\text{-}ai \cdot ha^{-1}$ (Table 7).

In a second study Draper et al. (1981) found 20% of the material sprayed at the edge of the spray block (0m). As well air samples were collected to predict inhalation exposure. Based on a rate of application of 560 g-ai•ha^{-1} the dermal exposure was estimated to be 48 μg•kg-BW^{-1} and the inhalation exposure to be 0.25 μg•kg-BW^{-1} at the edge of the sprayed area.

Lavy (1982) measured the exposure of observers located 20 to 150 m from the spray area during the helicopter application of 2,4-D. Although the exposure values in relation to the location of the observer were not detailed there was a narrow range of dermal exposures measured from 0.1 to 1.4 μg•kg-BW^{-1}. No inhalation exposure was detected for the workers. These figures result in a similar exposure estimate to those predicted for bystanders in the spray swath and up to 100 m from the spray boundary.

Worker Exposure (Fixed Wing Applications)

Numerous studies have been carried out to estimate exposure of those directly involved in agricultural aerial spray programs. There are generally more workers involved in an aerial operation with each person carrying out a specific task than in other types of agricultural spray operations. There are also more operational variables in aerial applications which need to be considered when making comparisons between studies. Although many studies do not provide sufficient detail to enable this to be done, the ones outlined in Table 8 did. In the study by Franklin et al. (1982) exposure was estimated for a pilot, a water carrier, a mixer/loader and two flagmen. The amount of 2,4-D contacting the skin on various parts of the body, the hand and in the breathing zone of the workers was measured as well as the amount of 2,4-D excreted in the urine. The total dermal and inhalation estimates and 2,4-D excretion are summarized in Table 9. The pilot had the lowest dermal deposition of the workers. The flagman had intermediate levels with greater deposition in the head and neck region. The mixer/loader has the highest dermal deposition with more deposition toward the wrists. On two of the days the mixer had the highest inhalation exposure but the air levels found were far lower than the TLV value of 10 mg/m^3. The authors concluded that the person with the greatest exposure was the mixer/loader who, in the course of preparing the spray solution could contact the concentrated 2,4-D. The major route of exposure to 2,4-D was to the skin; up to 99% of the total exposure as compared to the inhalation route. The urinary metabolite data also reflect the relative order of exposure as indicated by the patch data. The mixer/loader had the highest rate of excretion of 2,4-D followed by the flagman and pilot.

In a study by Peoples (1979) mixer/loaders, pilots and flagmen were monitored for dermal and inhalation exposure to the insecticide tributyl phosphorotrithioite (DEF, Folex). The monitoring periods ranged from 5 to 7 h and the results of these monitoring periods were used to estimate a 7 h work day exposure (Table 9). Although the mixers used closed systems to transfer the pesticide from the original container to the mix tank, it was noted by the authors that some closed systems required more maintenance than others possibly resulting in exposure levels higher than anticipated. Again, it was seen that the mixer/loader received the highest exposure, followed by the flagman and pilot. Pilots do not participate in mixing but it was observed that they do adjust the nozzles without wearing gloves. Regardless of duty performed, exposure to the hands was a major source of contamination for all workers.

In a study by Maddy (1982) mixer/loaders, pilots and flagmen were monitored during the aerial application of phosdrin (Mevinphos). Monitoring intervals ranged from 0.97 to 2.18 h and the results of these monitoring periods were used to estimate a 7 h work day exposure. Closed systems were used to transfer the pesticide from the original container. The mixer/loader and the flagmen had the similar levels of exposures (0.4 and 0.5

$\mu g \cdot kg\text{-}BW^{-1} \cdot lb\ ai^{-1}$) and the pilots had the lower levels of exposure (0.07 $\mu g \cdot kg\text{-}BW^{-1} \cdot lb\ ai^{-1}$). Again, the greatest amount of the dermal exposure was to the hands. Inhalation exposure was higher in this study than was seen in other studies.

Everhart (1982) monitored workers during the mixing and loading of aircraft with Benlate. The weight of Benlate mixed by each worker ranged from 25 to 60 lb. Under these conditions mixers received an average dermal exposure of 15.7 $\mu g \cdot kg\text{-}BW^{-1} \cdot lb\ ai^{-1}$ with 90% of this depositing on the hands and forearms. Inhalation exposure contributed only a minor amount to the total exposure.

Worker Exposure (Helicopter)

In a study where 2,4-D was applied by helicopter to forests (Lavy, 1982), three crews, each consisting of a helicopter pilot, mechanic, batchman/loader, supervisor and two observers were monitored in two separate trials carried out approximately 1 week apart. It was found the batchman/loaders, pilots and mechanics usually showed some degree of exposure whereas the observers (outside the spray area) showed little or none (Table 9). Although the patch data indicated a much higher level of exposure to the mixer/loader than the pilot, their urinary metabolite levels were similar. However, it was noted in the study that pilots adjusted spray nozzles without hand protection and it was suggested that this activity accounted for their urinary metabolite levels.

The effect of the use of protective clothing can be seen in both the patch based estimates of dermal exposure and the urinary metabolite levels. In the first trial workers used no special protective clothing or equipment while in the second trial all workers wore Tyvek coveralls, and mixer/loaders wore impervious gloves and boots, clean hats, and goggles. In all cases both the dermal and urinary metabolite levels were lower when additional protective equipment and clothing was used.

In general all workers associated with the helicopter spray operations had lower exposure levels as measured by the patches than those of comparable workers involved with fixed wing applications. However this is not reflected in the urinary metabolite levels which are in close agreement regardless of the mode of application. This discrepancy illustrates that patch data alone may be an unreliable estimator of worker exposure.

There are several other studies on exposure in aerial applications, but information on critical parameters which might influence exposure such as formulation type, rate of application, acres treated and total amount of pesticide handled was not provided. This precludes the possibility of direct comparison with other studies. Nevertheless these data can be used to generalize about exposure relationships between different work tasks.

Nash (1982) studied the absorption of 2,4-D by workers following the application of 2,4-D to wheat using ground and aerial equipment. Unfortunately 24 h urine samples were only collected on alternate days making the excretion data difficult to relate to the exposure period. Nevertheless in relative terms it was seen that the mixer/loaders excreted 3 times (19.6 $\mu g \cdot kg\text{-}BW^{-1}$ compared to 6 $\mu g \cdot kg\text{-}BW^{-1}$) the amount of 2,4-D that was excreted by the pilots. The relative values bear a relationship to those found in the study by Frankin et al. (1982) where mixers/loaders excreted more 2,4-D than pilots.

Atallah (1982) monitored applicator personnel during ground and aerial applications of EPN to cotton crops. In this study workers were monitored for at least one cycle and this was extrapolated to exposure for an eight hour day. The amount of pesticide sprayed or handled during the monitoring period was not given in the study. Based on an 8 h work day dermal exposures were 1.7 $mg \cdot kg\text{-}BW^{-1}$ for flaggers, 0.1 $mg \cdot kg\text{-}BW^{-1}$ for loaders and 0.03 $mg \cdot kg\text{-}BW^{-1}$ for pilots. The dermal exposure comprised the majority of the total exposure with 8 h respiratory expouures amounting to 4.5 $\mu g \cdot kg\text{-}BW^{-1}$ for flaggers, 0.2 $\mu g \cdot kg\text{-}BW^{-1}$ for loaders and 0.2 $\mu g \cdot kg\text{-}BW^{-1}$ for pilots.

In a study by Maitlen (1982) agricultural workers involved in the application of carbaryl by boom sprayer, hand gun and helicopter, mixers, and flaggers for the helicopter applications were monitored for dermal exposure. As the mixing operation was not inherently different regardless of application equipment, all mixing trials for similar formulations were used to compute an average dermal exposure. Rates of application and the formulations were given for each of the thirteen separate helicopter applications to corn but the total acreage and amount of carbaryl sprayed during each trial were not included. For the purposes of comparison all exposures were extrapolated to an exposure for a 7 h day. It was shown that during handling of powdered formulation mixer/loaders received an exposure of 10.7 $mg{\cdot}kg\text{-}BW^{-1}$ and the use of gloves reduced this to 4.3 $mg{\cdot}kg\text{-}BW^{-1}$ (based on a 70 kg body weight). The exposure resulting from mixing of liquid formulation was 4 $mg{\cdot}kg\text{-}BW^{-1}$ which was reduced to 0.3 $mg{\cdot}kg\text{-}BW^{-1}$ when gloves were worn. Exposure to the hands accounted for 76% of the dermal exposure. According to these trials the transferring and mixing of powder formulations resulted in a higher dermal exposure than when a liquid formulation was handled. Regardless of the formulation, the use of protective gloves lowered exposure to the hands.

The exposure to flaggers in the spray swath was 46.7 $mg{\cdot}kg\text{-}BW^{-1}$ which was considerably higher than that seen in other studies in which fixed wing aircraft were used. Flaggers located at the edge of the field had a lower dermal exposure of 17.6 $mg{\cdot}kg\text{-}BW^{-1}$. Unfortunately insufficient detail was provided on the helicopter spray nozzles, the positioning of the flagger, or environmental conditions to ascertain the meaning of these high values. It may be that a brief high exposure occurred as the helicopter passed by (the average exposure time was 2 minutes) but the extrapolation of the values from 2 minutes to a 7 h day exaggerated the figure and more realistically should have been based on the number of passes in the hour.

It was shown that the pilots had the lowest daily exposure of 0.7 $mg \cdot kg\text{-}BW^{-1}$ when wettable powder was used and 1.5 $mg \cdot kg\text{-}BW^{-1}$ with a liquid formulation. Almost all of the exposure was to the hands.

It is interesting to note that in both the studies by Maitlen and Atallah flagmen were not used in the normal spraying operation and persons "acting" as flagmen were added to the study. It is possible that inexperience of these people led to the high exposure or the extrapolation of the data may have led to these inconsistent data.

Lavy (1980) monitored workers during the helicopter application of 2,4,5-T ester. Limited measurements were made but the results indicate much lower exposure than in the other studies.

It can be established by the more detailed studies described in Tables 8 and 9 that a range in exposure values exist between workers carrying out various activities. Since exposure is ultimately related to the amount of material handled and there may be wide divergence in the time taken to spray a given amount, it has been recommended that the data be expressed in terms of the total kg of active ingredient sprayed rather than the hours taken to spray (Franklin et al. 1981).

Although the exposure methods and chemicals vary greatly between studies several conclusions can be drawn:

1. The greatest dermal exposure occurs to those persons contacting the concentrate in the course of their work (i.e. mixer/loader).
2. Dermal exposure is the primary route of exposure and only small amounts are inhaled.
3. The reliability of extrapolation of data from a portion of the workday to a whole workday has not been validated.

RISK ESTIMATION

To ascertain what these exposure levels mean in terms of health risk, they can be compared to the data from the toxicology studies. The "margin of safety" (M.O.S.) can be calculated by dividing the exposure level into the "no observed effect level" (N.O.E.L.) from the toxicity study (Table 10). One point that must be taken into account when viewing Table 10 is that it has been assumed that there is 100% dermal absorption.

Bystander Risk Estimation

In the aminocarb forestry situation the highest exposure occurred at the spray line and was primarily dermal, therefore dermal toxicity studies should be used for quantifying the risk. The most sensitive dermal LD_{50} for aminocarb is 148 $mg{\cdot}kg\text{-}BW^{-1}$ (NRCC, 1982). Using this value and an exposure of 1.9×10^{-2} $mg{\cdot}kg\text{-}BW^{-1}$ which was the highest bystander exposure, the M.O.S. is 7800 (Table 10). It would be desirable to compare the exposure to a N.O.E.L. rather than to the LD_{50}. Unfortunately NOEL's are rarely established in acute studies and to use a NOEL from a subacute exposure when the bystander exposure is acute is unduly cautious. However, it can be shown that even under these extreme conditions, using the lowest NOEL from a 21 day dermal study in rats (30 $mg{\cdot}kg\text{-}BW^{-1}$) still provides a M.O.S. of 1579. The parameter upon which the NOEL was set was cholinesterase depression and a margin of 100 has been considered acceptable (Lehman and Fitzhugh, 1954). The process whereby safety factors are utilized to establish acceptable levels of human exposure has been endorsed by the World Health Organisation and the magnitude of the safety or uncertainty factor depends upon the severity of the toxicological lesion. In reality the margin is even greater because the model presumes 100% absorption of the aminocarb and this is not true (Franklin, 1984 unpub.). The potential risk to the bystander to this type of operation is therefore considered to be negligible.

The highest estimated bystander exposure to 2,4-D in the forestry and prairie scenarios was 1.4 $\mu g \cdot kg\text{-}BW^{-1}$ (Table 6). The dermal LD_{50} is > 2000 $mg \cdot kg^{-1}$ and this leads to a M.O.S. of over 1 million. Using the most sensitive N.O.E.L. from a 90 day oral study in rats of 10 $mg \cdot kg\text{-}BW^{-1}$, the margin of safety is greater than 7000. Although it was estimated that multiple swaths would double the exposure at 50 m (NRCC, 1983), the reduction of the margin of safety to 2500 is not significant. Corrections for dermal absorption, which have not been made would increase these margins even further.

Worker Risk Estimation

As anticipated the margins are not as wide for the workers but appear to be more than adequate for all of the products with the exception of phosdrin where the margin for flagmen is only 33 instead of the desired 100 fold. Interestingly, the cholinesterase levels were normal in these workers suggesting that these crude estimates of margin of safety are too sensitive. This however is the prudent way to handle these data and the methods should not be modified until there are better data upon which to place confidence. A similar situation existed with regard to DEF a product which has not been registered in Canada. Lotti (1983) measured the exposure of a crew consisting of a pilot and a mixer/loader/flagger using DEF on two occasions. To correlate possible biochemical and physiologic effects, neurotoxic esterase (NTE) in lymphocytes was measured before and during exposure and peripheral nerve function (EMG) and nerve conduction velocity were measured before and after exposure. The investigators found that the dermal and inhalation exposures compared well with the results of Peoples (1979) when the data were normalized to a 7 h day. However, Lotti found that flaggers had a 10 fold greater deposition on their hands than in Peoples study which was attributed to handling empty containers. The exposures did not result in any detectable subclinical effect on the peripheral nervous system. Exposures did effect lymphocyte NTE. Both the intensity and the length of exposure seemed to be important in determining the inhibition of NTE in lymphocytes which was about 50% of the pre-exposure values when measured 3 to 4 weeks after the beginning of exposure. Blood acetylcholinesterase and plasma butylcholinesterase levels did not change during the study period. The level of NTE inhibition did not have any associated detectable electrophysiologic effects. Again the MOS calculation appears to have been overly sensitive.

In summary, using these examples, the exposure and concomitant risk to everyone potentially involved in the spray operation appears to be within acceptable limits. From these studies it was observed that the highest exposure and therefore the highest potential risk was to the mixer/loader followed by the flagman, the pilot and then the bystander.

These estimates also point to areas that could be emphasized in developing risk management strategies. Since the mixer/loader had by far the highest exposure, steps taken to minimize exposure in this operation would have significant impact on reducing overall exposure.

TRAINING AND LICENCING

In the discussion of exposure it was shown that changes in operating parameters could affect the levels. The computer-derived estimates for bystander exposure where based on conditions defined as "ideal" and did not consider problems caused by irregular spray patterns, spillage and leakage of the pesticide during mixing and loading, incorrect mixing and emergency dumping or crashing.

This emphasizes the importance of the training and licencing of aerial applicators to ensure that the large margins of safety that have been calculated do exist in practice. It is important that aerial applicators understand the conditions that lead to drift and how it may be minimized, how to properly calibrate their equipment to avoid over spraying and the importance of applying the material strictly to the target. The urban encroachment on rural land further emphasizes the need for good application techniques.

In a survey of all 10 provinces it was shown that 6 had a specific class of licence for aerial applicators (Table 11). However, in two of these six provinces there is no specific education or training given to aerial applicators to earn the licence. The requirement for an aerial applicator to have a licence varies with the use situation. Generally, when an applicator sprays aerially for remuneration in an agricultural or forestry setting, a valid aerial applicator's licence would be required. This would include farmers granted Flying Farmer exemption by the Canadian Transport Commission to apply pesticides for remuneration within a 25 mile radius of their own land. Where a farmer applies aerially on his own agricultural land, he would be exempt from any training and licencing requirements except in the province of New Brunswick. Here an aerial licence and a permit would be required from the Ministry of the Environment. Unfortunately, the aerial applicator licence has no educational or training requirements but the province plans to implement such requirements in the future. To ensure safe and effective aerial application of pesticides it would be ideal if the requirements for commercial aerial applicators were applicable to all aerial applicators regardless of what land would be treated. All provinces should have a functional aerial applicators course or require attendance at an existing course and have a mechanism to evaluate licencing candidates.

An alternative mechanism for controlling aerial pesticide use in the provinces is to require a use permit. Table 12 summarizes the applications which require a provincial use permit. In issuing the permit, variable parameters are considered for setback requirements. In most cases a minimum distance from waterbodies is specified for any permit use. In New Brunswick, Nova Scotia and Quebec where the control of the use of pesticides is mainly by issuance of permits, the permit specifies setbacks from not only waterbodies but permanent dwellings and roadways. In New Brunswick these setbacks are modified based on the toxicity of the pesticides and the drift potential of the formulation. Both the environment and human health could be better safeguarded if all provinces included setbacks to minimize bystander exposure based on the toxicity of pesticides used in their province.

All provinces have the provision for inspectors to enforce the requirements of the Acts and Regulations (Table 13). Penalties for violations under the Act and Regulations range from fines to imprisonment or both. One improvement that could be made would be to have the more specific requirements for setbacks on each permit and in every province make it an offence to apply pesticides other than those specified on the permit.

In summary, most provinces have the potential to require education, training and licensing of aerial applicators. To ensure that the comfortable margins of safety exist for applicators and bystanders, training and licensing of aerial applicators should be considered an important risk management strategy in all provinces. In recognition of this fact, efforts are being made by the provincial and the federal governments to develop core educational packages which will ultimately lead to a national standard for licensing pesticide applicators.

FUTURE DIRECTIONS

Toxicology Database

- the escalating costs of conventional animal studies will probably lead to increasing emphasis on pharmacodynamic, metabolic and mechanistic studies to ensure selection of proper animal models.

- the in vitro test systems should be validated against an adequate number of substances previously tested in animals.
- there should be development of techniques to assess the more subtle aspects of nervous system damage, and to better define the role of and effects on the immune system.
- the mechanism of carcinogenesis should be elucidated to enable a more meaningful quantitative risk assessment to be conducted.

Exposure Studies

- sufficient details should be provided to enable comparisons to be made between studies.
- it should be ascertained whether the mixer/loader exposure is consistently the highest with the dermal route accounting for the bulk of the exposure. This would allow more meaningful risk strategies to be developed (i.e. closed system delivery, protective equipment, formulations).
- more emphasis should be placed on developing alternate methods to monitor exposure to replace patches which frequently provide inconsistent data.
- more information on specific metabolic pathways in humans is needed and the relationship between excreted levels and level of exposure are necessary if metabolites are to be an estimator of exposure.
- a better understanding of percutaneous penetration is needed to relate contact exposure level to absorbed dosage. The importance of parameters such as species, site of application, formulation ingredients, temperature, humidity and uv light needs to be delineated.
- the practice of manual flagging should be discontinued.

Education, Training and Licensing

- all provinces should have a specific class of licence for aerial applicators stressing the importance of minimizing drift and exposure.
- anyone applying a pesticide by air should have to be licenced.
- all farmers applying pesticides aerially should have the same training and licencing requirement as commercial aerial applicators.
- permits should be required for aerial application and they should addr[illegible] both human health and environmental concerns. Setbacks should reflect toxicity of product and knowledge of drift potential.
- the provinces when issuing permits should state the limitations on the permit (i.e. maximum windspeed, effect of precipitation) and it should be a violation to apply a pesticide in a manner other than that stated on the permit.

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Table 1: Definition of risk assessment and risk management

- characterization of potential adverse health effects resulting from exposure to environmental hazards	- process of evaluating alternative regulatory actions
- may be qualitative and/or quantitative	- decision making process choosing amongst alternatives to select appropriate regulatory response

Adapted from Stallones, 1983

Table 2: Steps in risk assessment

1. Hazard Identification
    - predictive animal toxicity data, in vitro testing, epidemiology
2. Dose-Response Relationship
    - high dose - low dose extrapolation
3. Exposure Assessment
    - magnitude, duration, frequency, route, population affected
4. Risk Characterization
    - estimation of health effects under the conditions of exposure
    - utilizes dose-response and exposure data

Adapted from Stallones, 1983

Table 3: Acute toxicity tests required for registration (Technical and formulations)

LD_{50} - oral, dermal, inhalation

Irritation - dermal, eye

Sensitization

Delayed neurotoxicity

Table 4: Subacute toxicity tests required for registration (Technical and formulations)

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90 day oral (rat and dog)

12 month oral (dog)

90 day dermal

90 day inhalation

Delayed neurotoxicity (if acute test positive)

Table 5: Long term and special tests required for registration (Technical)

Chronic feeding (rat)
Oncogenicity (rat and mouse)
Pharmacokinetic (appropriate routes)
Mutagenicity
Teratology
Multi-generation reproduction
Exposure

Table 6: Estimates of bystander exposure from a field-validated computer model

		Dermal Exposure (μg kg-BW^{-1})			Inhalation Exposure (μg kg-BW^{-1})			Oral Exposure (μg kg-BW^{-1})			Total Exposure (μg kg-BW^{-1})		
m*	Wind speed m s^{-1}	Prairie 2,4-D [a]	Forestry 2,4-D [b]	Forestry Aminocarb [c]	Prairie 2,4-D [a]	Forestry 2,4-D [b]	Forestry Aminocarb [c]	Prairie 2,4-D [a]	Forestry 2,4-D [b]	Forestry Aminocarb [c]	Prairie 2,4-D [a]	Forestry 2,4-D [b]	Forestry Aminocarb [c]
0	0.5			7			$9x10^{-4}$			$1x10^{-2}$			7
	1.0												
50	1.5	$2x10^{-2}$	$6x10^{-1}$		$6x10^{-6}$	$3x10^{-1}$		$1x10^{-3}$	$2x10^{-1}$		$2x10^{-2}$	$8x10^{-1}$	
	3.0	1.4			$4x10^{-6}$			$8x10^{-4}$			1.4		
400	0.5			$3x10^{-3}$			$8x10^{-5}$			$1x10^{-2}$			$2x10^{-2}$
	1.0			$3x10^{-1}$			$7x10^{-5}$			$7x10^{-3}$			$3x10^{-1}$
	1.5	$1x10^{-4}$	$9x10^{-3}$		$8x10^{-7}$	$2x10^{-3}$		$6x10^{-5}$	$9x10^{-3}$		$2x10^{-4}$	$2x10^{-2}$	
	3.0	$8x10^{-3}$			$5x10^{-7}$			$6x10^{-5}$			$8x10^{-3}$		
800	0.5			0			$5x10^{-5}$			$8x10^{-3}$			$8x10^{-3}$
	1.0			$7x10^{-1}$			$3x10^{-5}$			$4x10^{-4}$			$7x10^{-2}$
	1.5	$3x10^{-5}$	$3x10^{-4}$		$4x10^{-7}$	$8x10^{-4}$		$2x10^{-5}$	$5x10^{-3}$		$5x10^{-5}$	$6x10^{-3}$	
	3.0	$3x10^{-3}$			$2x10^{-7}$			$2x10^{-5}$			$3x10^{-3}$		

From NRCC Aminocarb 1982, NRCC 2,4-D 1983

*Distance from sprayline

Application rate

[a] 1960 g-ai ha^{-1}

[b] 1680 g-ai ha^{-1}

[c] 70 g-ai ha^{-1}

Table 7: Summary of field data available to validate computer estimates of bystander exposure

	Product	Rate of Application (g-ai·hai^{-1})	m*	Exposure (μg·kg-BW^{-1})	
				Dermal	Inhalation
Fixed Wing (Agricultural)					
Draper (1981)	Furadan	560	0	48	0.25
Draper (1981)	Methyl parathion	280	50	12	-
Helicopter (Forestry)					
Lavy (1982)	2,4-D	2240	20-150	0.1-1.4	nd

- not measured

nd not detected

* distance from sprayline

Table 8: Summary of operational conditions for studies involving aerial application of pesticides

	Product	Rate of Application (lb-ai·A^{-1})	Total a.i. Applied (lb)	Spray Equipment	Nozzle	agl* and Crop	Acres Sprayed	VMD** (μm)
Fixed Wing								
Franklin (1982)	2,4-D LV (2,4-D iso octyl ester)	1.5-2 in water	300-1320	Thrush Commander (swath 20m)	36 Whirl jet nozzles with orifices from #2-10	13-21 brush	200-900	160 180 170
Peoples (1979)	Folex (DEF)	1.3 in water	1320	Turbo Prop	Whirl jets 1/8 BIO	10 cotton	1000	425
Maddy (1982)	Phosdrin 4EC (mevinphos)	0.5 in water	17-55	-	-	10 onions	35-120	-
Everhart (1982)	Benlate 50WP (benomyl)	-	12.5-30	-	-	-	-	-
Helicopter								
Lavy (1982)	Esteron 99 (propylene glycol butyl ether ester)	2.0 in oil and water	200	Helicopter	-	-	100	-

*above ground level in feet
**volume mean diameter

Table 9: Summary of dermal and inhalation exposure and urinary excretion values for workers involved in aerial operations

	Mixer/Loader (μg kg-BW^{-1} lb ai^{-1})			Flagman (μg kg-BW^{-1} lb ai^{-1})			Pilot (μg kg-BW^{-1} lb ai^{-1})		
	Dermal	Inhalation	Urinary[a]	Dermal	Inhalation	Urinary[a]	Dermal	Inhalation	Urinary[a]
Fixed Wing 2,4-D (Franklin)	0.06-4.1 (x_3=1.9)	$9x10^{-5}$-$8x10^{-4}$ (x_3=$4x10^{-4}$)	0.02[b] (38.8)[c]	0.02-1.1 (x_6=0.7)	$3x10^{-5}$-$3x10^{-3}$ (x_6=$1x10^{-3}$)	x_2=0.002[b] (4.4)[c]	0.01-0.04 (x_3=0.03)	$3x10^{-5}$-$3x10^{-4}$ (x_3=$1x10^{-4}$)	0.004[b] (9.7)[c]
Folex (Peoples)	0.1-1.3 (x_{10}=0.4)	-	-	0.02-1.1 (x_{11}=0.3)	-	-	0.05-0.2 (x_{11}=0.1)	-	-
Phosdrin EC (Maddy)	0.06-1.1 (x_4=0.4)	0.02-0.2 (x_4=0.05)	-	0-3.2 (x_8=0.5)	0-0.2 (x_8=0.06)	-	0-0.3 (x_4=0.07)	0.01-0.2 (x_4=0.06)	-
Benlate WP (Everhart)	3.1-34.4 (x_8=15.7)	$2x10^{-6}$-$1x10^{-4}$ (x_8=$6x10^{-5}$)	-	-	-	-	-	-	-
Helicopter 2,4-D (Lavy)									
no protective clothing	0.01-0.5 (x_3=0.2)	n.d.-$2x10^{-3}$ (x_3=$6x10^{-4}$)	x=0.09 (x_3=19.5)[c]	-	-	-	n.d.-0.04 (x_3=$2.8x10^{-3}$)	n.d.	x=0.1 (x_3=19.9)[c]
protective clothing[d]	$8x10^{-4}$-0.1 (x_3=0.05)	n.d.	x=0.07 (x_3=14.0)[c]	-	-	-	n.d.-$5x10^{-4}$ (x_3=$1.7x10^{-4}$)	n.d.	x=0.04 (x_3=8.5)[c]

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a acid equivalent

b urine collected during 3 spray days and the 5 days following

c total μg/kg excreted

d coveralls, gloves, boots, hat, goggles

Table 10: Risk estimation for bystanders and workers

Product	Dermal LD_{50} ($mg\text{-}kg\text{-}BW^{-1}$)	Margin of Safety			
		Bystander	Mixer/loader	Flagman	Pilot
Fixed Wing					
2,4-D	> 2,000	> 1 × 10^6	550	2512	76,923
Folex	615	-	362	439	2,356
Phosdrin EC	4.2	-	247	33	1,021
Benlate	10,000	-	26,954	-	-
Aminocarb	148	7800	-	-	-
Helicopter					
2,4-D	> 2,000	-	44,643	-	4 × 10^5

Table 11: Pesticide licensing requirements for aerial applicators

Province	Special Class	License Requirement		
		Agricultural Aerial		Forestry
		Farmer	Commercial**	
B.C.	no but licensed* in use category (ie: herbicide)	exempted except for schedule I	use category	use category
Alta.	yes plus license in use category	exempt	aerial plus use category	aerial plus use category
Sask.	yes	exempt	aerial	aerial
Man.	yes	exempt	aerial	aerial
Ont.	yes	exempt	aerial	aerial
Que.	no*	no	certificate of authorization	certificate of authorization
P.E.I.	yes*	exempt	aerial	aerial
N.B.	yes*	aerial	aerial	aerial
N.S.	no*	permit required	permit required	permit required
Nfld.	no*	exempt	general	general

*no specific training program for aerial applicators

**includes applicators spraying for remuneration who have been granted Flying Farmer Exemption by the Canadian Transport Commission

Table 12: Provincial permit and setback requirements for pesticide applications

Province	Permit Requirements	Setbacks
B.C.	1. public land 2. water 3. forests 4. right of way 5. schedule I	100 m from water bodies
Alta.	1. aquatic 2. experimental 3. forestry 4. restricted in regulations	30 m from water bodies
Sask.	aquatic	none
Man.	experimental use	none
Ont.	1. aquatic 2. fumigation 3. right of way - aerial and ground 4. forestry	"case by case"
Que.	1. aquatic 2. non agricultural aerial (<600 ha) 3. non agricultural aerial (>600 ha)* 4. right of way 5. non registered	minimum 60 m from sensitive zone (ie: houses, water, park etc.)
P.E.I.	1. aerial of restricted class 2. aerial of phenoxy 3. open body of water	25 m from water bodies

*environmental assessment required

Table 12: Provincial permit and setback requirements for pesticide applications (Cont'd)

Province	Permit Requirements	Setbacks	
N.B.	all except ground agricultural	Agricultural 1. 155 m from habitations for insecticides and 75 m from habitation for herbicides/fungicides 2. 50 m from property borders if drift may result 3. 65 m from open surface water	Forestry 1. 400 m from water 2. 3.2 km of municipal drinking water 3. 1.6 km from mobile or permanent homes for water based formulations 4. 3.2 km from mobile or permanent homes for oil based formulations 5. 400 m from ecological reserve
N.S.	1. right of way 2. forestry 3. aerial 4. industrial	Aerial 1. 300 m from prescribed water shed 2. not to contaminate surface water 3. 1.5 km from municipal water supply, lake, river or reservoir 4. 60 m from individual potable water supply 5. 30 m from road 6. windspeed less than 6 km/hr	
Nfld.	forestry	400 m from water "case by case" environmental assessment	

Table 13: Provision for inspectors and penalties for violations under provincial acts

Province	Inspection	Inspectors Duties	Fine	Imprisonment	for both	Repeat Offence
B.C.	yes	"administer requirements of Act and Regulations"	max $2,000	max 6 mos.	yes	same as first
Alta.	yes	"carry out provisions of Act"	max $1,000	max 90 days	yes	-
Sask.	yes	"carry out provisions of Act"	-	-	-	-
Man.	yes	"carry out intent of Act"	min $100 max $1,000	min 60 days max 6 mos		
Ont.	yes	"administer Act and Regulations"	max $5,000	-	-	max $10,000 each day
Que.	yes	"administer Act"				
P.E.I.	yes	"administer Act and Regulations"	max $1,000	90 days	yes	-
N.B.	yes	"carry out provisions of Act and Regulations"	max $1,000	max 100 days	yes	same penalty for each day of violation
N.S.	yes		max $5,000	-	-	max $10,000 for each day of violation
Nfld.	yes	"carry out provision of Act and Regulations"	max $10,000	-	-	max $10,000 each day of violation

Paper No. II-C

FLIGHT SAFETY CONCERNS

A.J.W. Melson
Aeronautical Engineering Specialist
Aviation Safety Engineering
Aviation Safety Bureau
Transport Canada
Ottawa, Ontario K1A 0N8

ABSTRACT

Statistical data for the 166 accidents to agricultural aircraft in Canada for the years 1976 to 1982 are presented showing various factors involved in the accidents on record.

Examples of accident reports involving agricultural aircraft are reviewed. An attempt is made to compare two types of aircraft used for aerial spraying: one a General Aviation aircraft adapted for agricultural use, and the other an aircraft designed for agricultural use. The accident rates and the crashworthiness of each type is determined and compared.

INTRODUCTION

This paper presents some of the safety aspects of aviation in agriculture through statistical data, illustration of some accidents, and a comparison of the crashworthiness of aircraft designed for agricultural use to general aviation aircraft which might be adapted for agricultural use.

Statistical Data

Statistical data on accidents during agricultural operations were obtained from the Information Superintendent of Aviation Safety Investigation of the Ministry of Transport (MOT). There were 166 accidents reported from 1976 to 1982 in Canada. The number of accidents per year ranged from 10 to 33 (Table 1) but no significant trend was indicated by these data. Helicopters were involved in 14% of the accidents and the remaining 86% were fixed-wing aircraft.

One significant trend, however, was that the frequency of accidents maximized in June and July the peak season for agricultural operations (Table 2), an expected outcome since this is when the majority of field work is done. These two months accounted for 65% of the accidents.

The frequency of accidents within provinces closely paralleled the agricultural production in each region (Table 3). The Prairie provinces (Saskatchewan, Alberta and Manitoba) accounted for 58% of the total number of accidents. Again this is a situation that reflects the level of agricultural aircraft operations in the various regions.

Thus these data indicate that the accident situation is what would be expected. The frequency of accidents is related to the volume of operations in agricultural regions.

A wide variety of aircraft were involved in the accidents on record (Table 4). Six models however, accounted for 75% of the accidents. This situation no doubt reflects the number of each make in use for agricultural operations.

Aircraft involved in accidents were operated under two ATC license classifications; 65% were operating under aerial application and distribution licenses (7AAD) and the remaining 35% under private aerial spray licenses. The differences in the pilot injury index (Table 5) under these classifications tended to be slightly higher for private aerial spray licenses than for 7AAD licenses. Serious or fatal injuries were 32% compared to 24%. An important point is that over the 7-year period, agricultural aircraft operations resulted in 25 fatalities. This loss exceeds that of other individual farm hazards such as silo and manure gas which are treated very seriously in the farm community.

Damage to the aircraft involved in accidents ranged from none to the aircraft being destroyed. The data shows:

Aircraft Damage	No. of Cases	%
None	1	0.7
Minor	3	1.8
Substantial	128	77.0
Destroyed	34	20.5
	166	

Thus the majority of aircraft accidents (97%) resulted in substantial financial losses.

The type of license for agricultural pilots involved in accidents included most existing classifications but the majority of accidents involved pilots with commercial licenses (68%) followed by those with private licenses (15.6%). This situation is likely a reflection of the hours flown under the different licences.

Type of License	No. of Cases	%
Not reported	1	0.7
Senior	2	1.4
Airline	11	6.5
Helicopter	13	7.8
Private	26	15.6
Commercial	113	68.0
	166	

Individual accidents occurred at most phases of aerial spray flights (Table 6). Serious or fatal pilot injury occurred mainly during the swath run, take off and initial climb, procedure turnarounds or pull-up from the swath run. Frequency of serious or fatal injury at these points in the flight were similar.

Table 7 shows the phase of flight where the accidents on record occurred. These data show that the take-off run, take-off and initial climb, swath run, pull-up from swath run and procedure turnarounds accounted for a major portion (59%) of the accidents.

The total hours flown by the aircraft involved in accidents covered a wide range (Table 8). These data suggest that the frequency of accidents peaked for aircraft with a total flying time of 500 to 3000 hours which accounted for 52% of the accidents. The same data, presented by "hours on type", is shown in Table 9.

Hours flown by 5 aircraft types popular in agricultural applications are summarized in Table 10. These aircraft were involved in 112 accidents resulting in 9 fatalities (Table 11).

The types of occurrences covered a wide range (Table 12). The main causes were engine failure, collision with a hydro pole or wire, loss of control in flight and collision with a tree which collectively accounted for 66% of the accidents. Data for two aircraft (Table 13) demonstrate the variety of occurrences. Investigation of the recorded accidents produced findings that determined the top 20 factors causing accidents (Table 14). These factors account for 45% of the causes of accidents.

Accidents - Case Studies

The following three cases illustrate the outcome of accidents and point out important factors for pilot safety.

Dromader PZL M-18

This spray aircraft, manufactured in Poland, was on a fire fighting operation. At a low altitude and in a steep bank, the wing tip contacted a tree. The aircraft consequently crashed and was destroyed with no damage to the cockpit area (Figure 1). The pilot was using the shoulder harness and wore a crash helmet and he escaped uninjured. This illustrates the value of the integrity of the cockpit structure during a crash.

Piper Pawnee

This aircraft was spraying potato fields when the right wing contacted some trees. The aircraft crashed and was destroyed with only minor damage to the cockpit area. The aircraft flipped over on impact. The pilot used a shoulder harness and wore a crash helmet. He escaped unassisted and without injuries because the cockpit was intact.

Grumman 164 Ag Cat

This aircraft was spraying a tree lot and had an engine power failure. It crashed into the trees and caught fire. On impact the wings broke off and the upper wing fuel tank ruptured, spilling fuel onto the engine which caused a fire. The chemical hopper also ruptured causing spray chemicals to enter the cockpit, making evacuation extremely difficult because it was slippery. The pilot used the shoulder harness and wore a crash helmet, and was uninjured from impact forces, but received severe burns while escaping the aircraft unassisted. Thus it is critical that fuel and chemical systems maintain integrity during a crash.

Crashworthiness

The accident case studies demonstrate that an aspect of safety which must be considered is crashworthiness. The reduction of injuries and fatalities in aircraft operations is the major concern of aviation safety. Most of the effort to date has been in airworthiness design and in education and training to avoid accidents. However, accidents continue to happen and people sometimes get injuries which could have been reduced or avoided by making the aircraft more crashworthy. Agricultural aircraft may be taking the lead in the design of crashworthy structures.

Aircraft designed for agricultural use have some special design features to improve crash survival. These were first formulated by High DeHaven at Cornell University Medical College in 1942. These design parameters have been modified and improved and most have been adopted for agricultural aircraft. They are concerned with the following items:

a) forward fuselage structure must be crash resistant.
b) the use of energy absorbing structures.
c) outward bending structure.
d) locating the crew behind the wing and heavy items.
e) providing a collapse space between the engine and cockpit.
f) eliminating sharp objects in the cockpit.
g) providing the pilot with shoulder harness of high strength.
h) eliminate plowing tendency by the keel structure.
i) locating the fuel tanks remote from the cockpit.

To find out how crashworthy an agricultural aircraft is, a crashworthy evaluation was done on a Piper Pawnee PA-25 and Cessna 188 and C150 aircraft using the method devised by Arizona State University for their course on Aircraft Crash Survival[1]. For this system, numbers are allotted for the different crashworthy features and the total score is compared with an optimum number to get an overall rating. The research that produced these data was done for the military, and is summarized in their Crash Survival Design Guide.

Six basic factors are considered and weighted values are assigned to each. The percentages are based on their relative hazard potential which have been arbitrarily assigned (Table 15). Each of six factors is in turn broken down into sub-factors each having their own optimum numbers. For example, the 130 points for the crew retention system is broken down in Table 16 which shows the sub-factor scores for the 3 aircraft analyzed.

For existing aircraft, inadequate restraint systems and post crash fires have been equally responsible for injuries and fatalities in accidents so they were weighted at about 35% each. Poor scores on either of these items could indicate a critical situation from a crash survival point of view.

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[1] See references.

Following this procedure, the actual crashworthiness score for the 3 aircraft used in agriculture can be established (Table 17). The scores ranged from 72 to 78% of the optimum.

The crashworthiness ratings of several commercial aircraft and two homebuilt aircraft were found by this method several years ago for a paper that I presented to the Canadian Aeronautics and Space Institute. Such an analysis must consider the present emergency landing load factors of FAR 23 and FAR 25 and compare them with the human tolerance limits of the Crash Survival Design Guide (Table 18).

The crashworthiness scores for the six aircraft rated averaged about 60% (Table 19). Since this analysis was done, shoulder harnesses have been brought into use for crew members. This increases the rating to about 67%. Since no passengers are carried in agricultural aircraft, passenger retention, can be deleted. This causes the rating to go to about 72%. For the agricultural aircraft, improvements in restraint systems and airframe bring the rating close to 80%. Some of the areas where improvements can still be made are as follows:

(a) Energy absorbing seats that will deform without failure under loads less than the human tolerance level.

(b) Seat belts that ride down with the seats and remain snug.

(c) Greater post crash fire protection by fuel containment, automatic fuel line shut-offs and flexible fuel lines.

(d) Post crash containment of the spray chemicals or other payload.

At the present time there is no certification requirement to do these things because the aircraft already meet or exceed the FAR 23 certification requirements.

REFERENCES

Transport Canada Accident/Incident Data System

Accident Data File - Transport Canada, Moncton

Crash Survival Investigators School Manual - Arizona State University

Crash Survival Design Guide - National Technical Information Service, U.S. Department of Commerce.

Table 1. Number of Accidents Per Year

1976	27
1977	23
1978	24
1979	27
1980	10
1981	33
1982	22
Total	166

Table 2. Percentage of Accidents Per Month

April	7.0
May	13.0
June	38.5
July	26.0
August	9.0
September	3.0
October	3.0
November	0.5

Table 3. Accidents Within Provinces

Province	Number	% of Total
Saskatchewan	46	27
Alberta	35	21
New Brunswick	20	12
Quebec	20	12
Manitoba	17	10
Ontario	16	9
British Columbia	5	3
Prince Edward Island	4	2
Nova Scotia	3	1
Total	166	

Table 4. Number of Accidents by Aircraft Type and Model

Make and Model	No. of Accidents
Cessna 188	45
Piper PA25	37
Bell 47	13
Grumman G1645	10
Grumman TBM	10
Piper PA18	9
Cessna 172	5
Hughes 269A	5
NA Rockwell Thrush	5
Boeing Wich 75	4
Cessna 180	3
Aeronca 7	2
Hiller Aircraft 12	2
Luscombe 8	2
Piper PA36	2
Rockwell Thrush	2
Bell 206	1
Bell 212	1
Champion 7ECA	1
Champion 7GC	1
Champion 7GCB	1
Grummanamer G164S	1
Lockheed 749	1
Piper PA11	1
Piper PA28	1
Schweizer G164	1
Total	166

Table 5. Pilot Injury Index in Accidents by Aircraft License Classification

	Classification					
Injury Index	7AAD[1]		Private Aerial Spray		Combined	
	Cases	%	Cases	%	Cases	%
None	70	65	37	62	107	65
Minor	11	10	6	10	17	10
Serious	13	12	4	6	17	10
Fatal	13	12	12	26	25	15
Total	107		59		166	

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[1] Aerial application and distribution.

Table 6. Phase of Flight Resulting in Serious or Fatal Accidents

Phase of Flight	Serious	Fatal	Total
En route/swath run	1	6	7
Take off/initial climb	4	2	6
En route/procedure turnaround	3	4	7
En route/pull-up from swath run	4	5	9
En route/aerial work	1	3	4
En route/to and from aerial work area	1	1	2
En route/starting swath run flare out	1	1	2
En route/climb to cruise	1	-	1
Standing/idling engine(s)/rundown	1	-	1
En route/normal cruise	-	1	1
Approach and landing/level	-	1	1
Take-off vertical	-	1	1

Table 7. Phase of Flight Where Accidents Occurred

Phase	No. of Accidents	%
Swath run	26	15
Take-off - initial climb	22	13
Procedure turnaround	17	10
Pull-up from swath run	15	9
Take-off run	14	8
Aerial work	10	6
Landing roll	9	5
En route to/from work area	8	4
Final approach	8	4
Take-off aborted	7	3
Starting swath run	6	3
Normal cruise	6	3
Taxiing from landing	5	1
Carrying sling load	2	1
Climb to cruise	2	1
Level off/touchdown	2	1
Total	159*	

*7 Cases not listed

Table 8. Total Hours Flown by Aircraft involved in Accidents

Hours Flown	No. of Cases	%
100 - 199	1	-
200 - 299	4	2
300 - 399	11	6
400 - 499	11	6
500 - 999	33	20
1000 - 1999	20	12
2000 - 2999	26	16
3000 - 3999	12	7
4000 - 4999	13	8
5000 - 9999	20	12
10000 - 19999	8	5
20000 - 99999	1	-
Total	160*	

*6 Cases not listed.

Table 9. Hours on Aircraft Type that were Involved in Accidents

Hours	No. of Cases
Less than 5	2
5 - 19	11
20 - 49	13
50 - 99	19
100 - 199	28
200 - 299	19
300 - 399	12
400 - 499	9
500 - 999	31
1000 - 1999	8
2000 - 2999	3
3000 - 4999	1
5000 - 9999	2

Table 10. Hours Flown by 5 Aircraft Types that were Involved in Accidents

1976-1980

Aircraft Type	1976	1977	1978	1979	1980	Total
Cessna 188	10770	11683	12481	13496	12733	61163
Grumman 164	2435	3292	3784	2792	2919	15222
Piper PA25	10335	12556	12225	11459	12426	59001
Piper PA36	-	536	376	283	458	1653
Rockwell Thrush	1111	1855	1985	2547	2752	10250

Table 11. Accident Data for 5 Aircraft Types 1976-1980

Aircraft Type	Accidents		Total Hours Flown
	Total	Fatal	
Cessna 188	53	2	61163
Grumman 164	13	0	15222
Piper PA25	37	5	59001
Piper PA36	2	1	1653
Rockwell Thrush	7	1	10250
Totals	112	9	-

Table 12. Type of Occurrence Causing Accidents

Occurrence	No. of Cases	%
Engine failure malfunction	36	23
Collision with object-pole-wire	27	17
Loss of control in flight-mush-stall	23	13
Collision with object - tree	12	7
Loss of control on ground - water	9	5
Overrun	9	5
Controlled collision-level surface	6	3
Loss of control in flight - other	4	2
Collision with hill/mountain-controlled	3	1
Collision with object - fence-post	3	1
Dragged wing/rotor - pod/float	2	1
Nose over	2	1
Uncontrolled collision-level surface	2	1
Collision object - flagman - loader	2	1
Collision object - vehicle	2	1
Collision object - other	2	1
Collision object - crop	2	1
Spin	2	1
Fire	2	1
Propeller failure	2	1
Total	152*	

*14 Cases not listed.

Table 13. Types of Occurrences for 2 Aircraft Types (1976-1982)

Occurrence Type	No. of Accidents							
	Piper PA25/PA36				Cessna 188			
	Total	Fatal	Serious	Fire*	Total	Fatal	Serious	Fire*
Loss of control - stall	4	0	1	2	5	0	2	0
- spin	0	0	0	0	5	1	2	0
- other	1	0	0	0	0	0	0	0
- on ground	0	0	0	0	6	0	0	0
Collision level surface - controlled	2	0	0	0	3	0	0	0
- uncontrolled	0	0	0	0	1	0	1	1
Collision hill-mountain								
- control unknown	0	0	0	0	1	1	0	1
- controlled	0	0	0	0	3	0	0	0
Collision - wire - pole	3	2	0	1	5	0	1	0
- flagman - loader	2	1	1	0	0	0	0	0
- ditch	1	0	0	0	0	0	0	0
- earth bank	1	0	0	0	1	0	0	0
- crop	1	0	0	0	0	0	0	0
- fence	1	0	0	0	2	0	0	0
- tree	7	3	1	3	5	0	0	0
- struck by vehicle	1	0	0	0	0	0	0	0
- other	1	0	0	1	0	0	0	0
Failures - door - panels	1	0	1	0	0	0	0	0
- engine and malfunctions	9	0	0	0	5	0	0	0
- flight controls	0	0	0	0	1	0	1	1
- main gear	0	0	0	0	2	0	0	0
Flight Operations - overrun	3	0	0	0	5	0	0	0
- forced precautionary landing	1	0	0	0	0	0	0	0
- landing beside landing area	0	0	0	0	1	0	0	0
- nose over	0	0	0	0	1	0	0	0
- hard landing	0	0	0	0	1	0	0	0
Totals	39	6	4	7	53	2	7	2

*Post impact

Table 14. Top 20 Causes of Accidents 1976-1982

Cause	Factor	%
Pilot failed - to see or avoid objects	38	6
- to obtain/maintain flying speed	30	5
- to use adequate preflight preparation or planning	27	4
- to select suitable take-off, landing, taxiing area	18	3
- to follow procedures and instructions	14	2
Terrain - high obstructions	13	2
Pilot - diverted attention from operation of aircraft	12	2
- improper inflight decision or planning	12	2
Disregard of good operating practice	11	1
Other personnel - maintenance services - improper maintenance or personnel	9	1
Pilot - attempted operation beyond experience or ability	8	1
- improper compensation for wind	8	1
Terrain - rough uneven	8	1
Fuel exhaustion	8	1
Sun glare	8	1
Pilot misjudged altitude and clearance	7	1
Terrain - soft ground	7	1
Pilot - impaired by fatigue	7	1
- improper operation of power plant controls	6	1
- improper operation of brakes or flight controls on ground	6	1
Total of above factors	257	45
Total of remaining factors	312	55
Total of all factors	569	100

Table 15. The Six Basic Factors Considered in Evaluating Aircraft Crashworthiness

Factor	Hazard Potential %	Optimum Score[1]
Crew retention system	17.92	130
Passenger retention system	17.23	125
Postcrash fire potential	35.19	255
Basic airframe crashworthiness	17.23	125
Evacuation	8.29	60
Injurious environment	4.14	30
Totals	100	725

[1] An arbitrary number assigned for each factor

Table 16. Optimum Subfactor Scores within the Crew Retention Factor Showing Actual Scores for 3 Aircraft

Crew Retention	Optimum Score	Actual Score		
		C150	PA25	C188
1. Vertical Energy	10	0	0	0
2. Webbing	30	10	30	30
3. Seat Longitude	15	5	5	5
4. Seat Lateral	15	5	5	5
5. Seat Vertical	5	0	0	0
6. Castings	10	10	10	10
7. Shoulder Strap Guide	10	5	5	5
8. Shoulder Strap Angle	10	10	10	10
9. Lap Belt Angle	10	10	10	10
10. Lap Belt Tiedown	10	0	0	0
11. Inertial Reel	N/A	-	-	-
12. Depth of Structure	5	3	5	5
	130	58	80	80

Table 17. Crashworthiness Rating - Piper PA-25 Pawnee and Cessna 188, C150

Factor	Optimum Score	Actual Score		
		C150	PA-25	C188
Crew retention	130	58	80	80
Passenger retention	-	-	-	-
Postcrash fire	255	216	206	206
Basic airframe	125	93	110	110
Evacuation	60	50	50	50
Injurious Environment	30	16	23	23
	600	433	469	469
% of Optimum		72	78	78

Table 18. Emergency Landing Load Factors compared with Human Tolerance Limits According to the Crash Survival Design Guide (CSDG)

Direction	Load Factor		
	FAR 23.561	FAR 25.561	CSDG
Forward	9.0	9.0	40
Down	3.0	4.5	25
Side	1.5	1.5	20
Up	3.0	2.0	15

Table 19. Crashworthiness of 6 Aircraft compared with Optimum Scores in 6 Factors

Factor	Score						
	Optimum	Aircraft					
		1	2	3	4	5	6
Crew retention system	130	43	26	34	32	49	30
Passenger retention system	125	38	26	34	32	32	33
Post crash fire potential	255	170	205	216	207	204	190
Basic airframe crashworthiness	125	95	113	93	78	104	108
Evacuation	60	45	45	50	50	45	37
Injurious environment	30	21	23	21	21	22	20
Total	725	412	338	448	420	456	418
%	100	57	47	62	58	63	58

Figure 1. Dromader PZL M-18 Aircraft showing Intact Cockpit After the Crash.

Paper No. III-A

WEED CONTROL
PRESENT USAGE AND FUTURE TRENDS

R. Grover
Research Station, Agriculture Canada
Regina, Saskatchewan
S4P 3A2

ABSTRACT

The discovery of hormone-type weed killers in the late 1940's, such as 2,4-D and MCPA, established the selectivity principle as a practical approach for weed control in cropland. Since then the weed control technology has had several other breakthroughs. These include such advances as:

- introduction of substituted phenylureas and triazines and the associated spray technology to apply wettable powder formulations in the early 1960's,
- developments in the pre-plant incorporation techniques with volatile soil-applied herbicides, such as thiocarbamates and dinitroanilines in the 1960's,
- development of useful herbicide mixtures and the application of the selectivity principle for the control of wild oats in the 1970's.

These advances in weed control technology have led to the large-scale use of herbicides and raised concerns about their potential impact on environment and human health. There are demands for greater precision in spray technology to reduce or eliminate potential off-target drift hazards and lessen dependence on chemicals. The 1980's require a two-pronged approach to research and development in weed control technology:

- an analytical approach to application technology which will include: (a) improved definition of the target, (b) more precise biological requirements for dosage and optimum droplet size, and (c) control over droplet size production and deposition;
- an improved understanding of crop losses from weeds, costs, risks, and benefits to farmers, consumers, and the environment, based on critical evaluation of (a) the relative merits of alternative methods of weed control, including integrated pest management techniques, (b) annual costs of weed control vs. reductions in crop losses, and (c) maintenance of environmental quality along with concerns for conservation of energy and natural resources.

INTRODUCTION

The objective of this paper is to outline the requirements for weed control at the target, i.e. crop and/or soil, and to point out the potential for changes in current weed control practices in the future. Presumably, the discussion is expected to be based, on or at least related to, research carried out with aerial application methodology, preferably under Canadian conditions. Since about 80% of the aerial application of agricultural pesticides in Canada occurs in the prairies (Hay, 1981), it is logical to discuss this subject primarily from the prairies point of view. Less than 10% of the herbicides used in the prairies are applied by aircraft (Hay, 1981). Therefore, most of the ensuing discussion on the current practices and future potential changes in weed control technology in the prairies is based on research carried out with groundrigs. Even the current label claims, for herbicides specifically registered for use with aircraft, are based primarily on research with ground application technology, with minimal field testing using aircraft. This is especially true for older herbicides, such as 2,4-D, MCPA, etc.

CURRENT WEED CONTROL PRACTICES IN WESTERN CANADA

The current chemical weed control technology can only be appreciated in the context of its historical evolution, especially since the mid 1940's. Prior to this weed control with chemicals was largely non-selective, using soil sterilants, such as sodium chlorate, etc. Following the discovery of hormone type herbicides, such as 2,4-D, in the late 1940's, the selectivity principle as a practical approach for weed control in cropland was established. Since then the science of chemical weed control has had several breakthroughts, such as:

- the introduction of triazine herbicides which modernized weed control methods in corn in the early 1960's. In addition, the development of wettable powder formulations of these and phenylurea herbicides has led to more sophisticated spray equipment;
- the development of thiocarbamate and dinitroaniline herbicides, such as triallate and trifluralin in the 1960's which led to pre-plant and pre-emergent incorporation techniques, a new concept in crop management.

The 1970's saw a number of innovations, such as:

- a search for useful herbicide combinations or mixtures to improve and possibly enhance weed control as well as conserve energy by reducing the number of required applications,
- the use of the non-selective herbicide glyphosate in recirculating sprayers, roller and rope-wick applicators, to control tall weeds in crops which has added a new dimension to post-emergence application techniques,
- the application of the selectivity principle to the control of wild oats and other grassy weeds in cereal crops with herbicides such as, diclofop methyl, flamprop methyl, etc;

The advent of new herbicides, such as chlorsulfuron, with extremely low rates of application and wide spectrum of weed control in the early 1980's, is already providing new challenges in application technology.

These and other aspects of the rapidly changing technology of weed science were recently highlighted by Hay in his keynote Presidential address to the Weed Science Society of America (Hay, 1980). The continuing and rapid acceptance of this technology by farmers is well illustrated by the types and amounts of herbicides currently in use in western Canada alone. In addition, the number of herbicides for selective control of broad-leaved weeds, which are not killed by phenoxys, has proliferated over the last three decades (Table 1). The total usage of these herbicides in western Canada in 1982 was 5.075 million kg for phenoxy and 2.765 million kg for other such herbicides.

In 1963, only three herbicides were used to control wild oats on about 24,000 ha of cropland in western Canada (Hay, 1980). In 1982, there were about 10 different herbicides to control wild oats and other grassy weeds (Table 2). It was estimated that over 50% of the cropland in the three prairie provinces was treated with herbicides in 1982 to control grassy weeds at an estimated cost of about $320 million (Table 2).

Any of these herbicides can be applied by aircraft, provided there is no contra-indication on the label prohibiting their use by aircraft (Anon, 1981). However, more recently the registrants are being encouraged to outline the appropriate use directions and precautions for aerial application on currently registered products. Registrants of new active ingredients are now expected to provide 'data and/or document field experience' to support directions for aerial use (Anon, 1981). As a result of this policy, several herbicides are currently registered specifically for aerial use (Anon, 1984). These include old established herbicides such as barban, bromoxynil, 2,4-D, MCPA, and triallate as well as some of the new herbicides, such as diclofop methyl, difenzoquat and flumprop methyl.

BASIC REQUIREMENTS FOR CHEMICAL WEED CONTROL

From the agronomist's point of view, the basic requirements for chemical weed control can be stated simply as the application of the right herbicide, in the right place, and at the right time or right stage of the weed(s) and/or crop(s) growth. Even from an applicator's point of view, the basic requirements for weed control at the target can be stated again simply as the ability of the application machine, whether ground-rig or an airplane, to travel on or above the target, measure and/or monitor the herbicide, and disperse and/or aim the product with a view to discharging it on to the crop and/or soil, with minimal contamination of the environment. Thus, both the correct timing and correct application are basic to maximum exploitation of the selectivity principle.

In spite of the awareness of the selectivity principle as the basis of modern weed control practices, many current weed control practices are still based on empirical herbicide testing methods. The ideal weed control technology, which would permit just the 'right' amount of the inhibiting and/or lethal dose to be placed only on the 'competing' weeds, with none of the herbicide reaching any of the unintended targets, is still a desirable objective, yet to be achieved.

FUTURE TRENDS IN WEED CONTROL RESEARCH

The rapid advances in weed control technology over the last three decades and the resultant large scale use of herbicides has led to concerns about their impact on human health and the environment. There are also demands for precision in spray technology to maximize deposition on targets as well as research on alternate methods of weed control, with less dependence on chemicals.

Space does not permit discussion in detail of many of the research requirements that are either under way or are needed to resolve current issues in weed science. However, several of these may be categorized as follows:

Weed Biology and Physiology

- developing herbicide resistant crops by genetic engineering,
- recognizing development of resistence to herbicides in weeds and the mechanisms involved,
- recognizing environmental condition(s) that may enhance/reduce herbicide effectiveness, and eventually determine the 'right' dose,
- defining critical developmental and physiological stages of weeds to optimize timing and dosage requirements as well as enhance translocation in the target,
- understanding germination mechanisms with a view to reducing the longevity of weed seeds, etc.

Weed Ecology and Weed Surveys (monitoring)

- understanding the recurrence and spread of weeds on individual fields, within and between farms, within communities and even across national borders e.g. weed surveys of Canadian provinces,
- evaluating the influence of multi-specie weed communities on crop production at the farm level,
- understanding the dynamics of weed populations at the farm level to determine why weeds susceptible to commonly used herbicides are not being controlled, etc.

Economic Assessment and Risk/Benefit Analysis

- accepting 'containment' rather than 'eradication' as a basis for economic assessment,
- developing models to predict potential economic impact of weed communities on crops at the farm level by:
  - expressing the ecological impact in economic terms,
  - comparing the short and long-term costs of weeds to the costs of control,

- evaluating the non-ecological factors, such as:
    - cost impacts of weeds on crop grade and marketability,
    - cost of weeds as a potential hinderance to harvesting operations, etc.

Herbicide Chemistry, including Formulation

- continuing development of highly potent compounds with a wide spectrum of weed control, such as chlorsulfuron, which will require precise application technology,
- manipulating formulation chemistry to regulate persistence, improve delivery to the target, and reduce vapour losses,
- exploiting metabolic processes to enhance uptake and translocation in the target,
- establishing 'mass balance', or 'accountancy' of herbicides under large scale field conditions (initial partitioning and subsequent dissipation from the soil,air,crop components),
- developing 'safeners' to manipulate weed/crop susceptibilities,
- manipulating formulation chemistry to enhance compatibilities within mixtures, etc.

Alternative Strategies for Control

- developing biological agents, such as insects and diseases, to control weeds, including application of 'bio-herbicides',
- developing synthetic herbicides related to natural toxins (allelopathy),
- testing phytotoxicants from micro-organisms (Herbimycins, herbicidines), etc.

New Developments in Application Technology

- developing control of droplet production and deposition,
- requiring more precise definitions of the target and the dose,
- requiring information on the interactions of volume, droplet size, number of droplets/unit area, and rate for various weed and crop species and for ground-rig and aerial application technology (efficacy and crop tolerance),

- assessing ground-rig vs aircraft requirements for crop tolerance as well as efficacy,
- developing control of drift, especially from application by aircraft, etc.

New Concepts in Argronomic Management Systems

- developing herbicides for zero-till and reduced-till systems (conservation tillage),
- distinguishing the systematic approach to weed control based on sound scientific principles and rational strategies from the 'pragmatic destruction of weeds' (integrated weed management systems),
- developing integrated pest management systems (IPM), based on,
  - integration of several methods or procedures to control weed communities in commodities,
  - integration of weed management with other pest management technologies,
  - integration of weed and pest management systems with other management tools under an agro-ecosystem concept, etc.

It is apparent that weed control technology is entering a new era, requiring a highly inter-disciplinary approach to crop management and production systems. I have only briefly mentioned the new requirements for weed control research, with the potential introduction of new application technology. This and other aspects, such as interactions with environment and health and safety, are also being discussed in other papers.

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Table 1. Estimated use of herbicides in 1982 across western Canada to control broad-leaved weeds (Daciw 1983).

Herbicides		Kilograms	Kilograms
2,4-D	ester (butyl)	348,600	
	ester (octyl)	1,278,200	
	amine salts	1,531,600	
		3,158,400	3,158,400
MCPA	esters	289,100	
	amine salts	1,456,500	
	Na/K salts	171,000	
		1,916,600	1,916,600
			5,075,000
other	herbicides*	2,765,300	2,765,300
		Total =	7,840,000

* bromoxynil, dicamba, dichlorprop, linuron, glyphosate, propanil, picloram etc.

Table 2. Number* and estimated cost and hectarage treated with herbicides to control wild oats and other grassy weeds in cereal and other crops in the three prairie provinces (Todd 1984)

Province	Cropland Treated	Cost
	(ha)	($)
Alberta	2,941,683	98,525,212
Saskatchewan	4,531,385	151,348,250
Manitoba	2,103,752	70,265,316
Total	9,576,820	319,865,778

* asulam, barban, diclofop methyl, difenzoquat, EPTC, flamprop methyl, sethoxydim, triallate, trifluarlin.

Paper No. III-B

INSECT CONTROL: THE REQUIREMENTS AT TARGET

W.A. Charnetski
Research Station
Agriculture Canada
Lethbridge, Alberta
T1J 4B1

ABSTRACT

A historical review of the methods, techniques and equipment along with the benefits of aerial application to industry and/or society is presented. The review of the requirements for insect control at the target is restricted to field crops on the prairies. Consideration of both environmental and agricultural implications is summarized together with the influence of microclimate, insect size, insect position, crop canopy, spray droplet size, formulation and deposition pattern, and the physical parameters of the spray aircraft. An outline of the multidisciplinary direction of future research is discussed. For maximum effectiveness aerial application should be 'tailored' to specific control scenarios. A suggested outline of the multidisciplinary direction of future research is discussed.

Insect control with chemicals in Canada is achieved through the use of some 125 insecticides to control about 100 economically important species of insects. Although the number of hectares sprayed by aircraft cannot be accurately estimated, it is clear that the number could reach 5-10% of the total sprayed and is always increasing. The total area of agricultural crops sprayed for insect control by aircraft in Canada is approaching that sprayed in forests. However, the concerns for environmental safety and public health aspects are much greater because of the proximity to habitation, the relatively small blocks sprayed, and the very low aircraft-spray elevation used for agricultural crops. This low elevation, compared to forestry operations, dictates a substantial difference in the interaction with the environment, spray generation and deposition, and airflow around and from the aircraft.

Historically, the Defense Research Establishment at Suffield maintained an extensive program on aerial application of insecticides. More recently, however, relatively little concerted work appears to have been conducted on aerial application of insecticides in Canadian agriculture. This is borne out by the dearth of quality scientific and readily available technical reports published on Canadian studies. One of the reasons for this lack of involvement may be the fact that, in the past, insecticides were granted registered use patterns on the basis of data obtained from ground application studies. The registration process now requires separate data for aerial and ground application. The potential exists to establish a strong interdepartmental program, with existing personnel, in the federal government.

The ultimate objective of any insect control program is the protection of the crop. The concerns within the program can be divided into three major categories namely; aeronautical, environmental, and agricultural. It is important, however, to establish that the environmental concerns are part and parcel of the agricultural. Successful agricultural production demands control of pest species when their populations reach economic thresholds. However, this control must not be achieved at the expense of the beneficial biological species.

For the purpose of this presentation, the term insecticide refers to any product or formulation used to control insects. These can include natural products, synthetic chemicals, and biologicals.

AGRICULTURAL CONCERNS

Within this context, this author assumes that factors such as aircraft type, pilot operation, boom configuration, spray pattern, and spray climate are optimized.

The aircraft must allow for maximum operational efficiency and allow the pilot to operate the aircraft in a configuration that will not impede the deposition of the chemical on target. The spray boom must be mounted for maximum delivery to target and should extend only to within one metre of each wing tip. An example of normal wing tip vortex action has been observed by most in the industry. However, National Research Council's National Aeronautical Laboratory, in Ottawa, has described a phenomena of 'bursting of vortex cores' using a specifically located smoke generator. Observaton of this bursting from photographic records raises several questions: What happens to this air flow under spray operations? Does it occur with all aircraft?

Spray nozzles should be the same size and be positioned along the boom so as to give a relatively even deposition pattern. Patternation of a spray plane is certainly no simple task. It is even more difficult when one must make sure that the pattern is adequate when flying 'in-out' as well as 'race-track' patterns. Figure 1 shows an actual spray pattern and Figure 2 shows the result of a computer simulation from this pattern for the 'race-track' (Fig. 2A) and 'in-out' (Fig. 2B) approach. The relatively good pattern, achieved when the three passes are made in the same direction, becomes totally unacceptable when successive swaths are made in opposing directions.

Climate considerations in Canada limit spraying to daylight flying. On the prairies, this time is usually further restricted to early morning and late afternoon/evening periods because of prevailing daytime winds (Fig. 3). Can the applicator assume a similar deposition on a cool crop in the morning, and a warmer crop in the evening?

FACTORS AT THE TARGET

Of the many factors that affect insect control at the target, consideration will only be given to the following:

- microclimate
- energy balance
- droplet size
- type of crop canopy
- location of insect
- insect growth phase
- chemical toxicity and susceptibility of the insect

Microclimatic factors such as temperature and relative humidity are important to evaporation of the carrier in the droplet and setting up of 'thermals' which influence droplet movement within the canopy. These factors together with the quality of light penetration can significantly affect the volatilization and/or degradation of the insecticide. All three factors play a major role in the efficacy of the chemical.

Tied to microclimate is the energy balance of the field. It is important to know whether the radiation energy is being absorbed by the crop and the soil or is being irradiated. Irradiated energy could be important to droplet movement within the canopy, or determine if it will reach the target at all.

The probability of hitting the targeted insect is greatly increased by the application of smaller droplets. Similarly, larger droplets can carry more toxicant than is required to kill a single insect, leading to a reduction in the number of insects killed at a specific application rate. The volume of a 500 µ droplet is equal to the total volume of eight 250 µ droplets and therefore the number of droplet equivalent volumes/cm^2 increases with reducing droplet diameter.

The type of crop, or the type of crop canopy 'architecture', is paramount to the degree of droplet penetration. Chemical penetration into an alfalfa and a barley canopy was significantly different (Fig. 4) when measured at 15 cm vertical intervals. The alfalfa canopy was completely closed and was not be moved by the bow wave caused by the plane. However, the barley canopy was open and first closed with the force of the bow wave action and then whipped back and forth, collecting a substantial portion of the spray by setting up horizontal air movement that restricted the downward movement of the droplets. The concentration of chemical in the top 15 cm can be used to advantage in the control of serious pest species like the bertha armyworm on canola or the wheat blossom midge and adult grasshoppers on cereals on the prairies. If insect pest control is shown to be economical on rangeland, the demands on aerial application will be significantly increased.

The canopy penetration or vertical distribution then becomes important in the control of insects which may be deep within a canopy. Most mobile insects move throughout the canopy. Description of these movements over time as influenced by various climatic and microclimatic conditions would be valuable to the establishment of more efficient control practices with reduced quantities of insecticides. Convention says that smaller droplets better penetrate a crop. In a monocotyledonous plant species there is little difficulty in reaching both sides of the leaf. In dicotyledonous plants, especially broad-leaved plants, coverage on the underside is very difficult if not impossible. Droplets larger than 200 µ diameter are thought to bounce off vertical leaves and splatter on or run off horizontal leaves. In controlling insects, other than soil-inhabiting species, a substantial portion of the active incredient would then be wasted.

Correlated to the location of the insect in the canopy is its growth stage. Younger stages are more susceptible and generally less mobile and therefore easier to control if the applicator can get the chemical to this target. This requires application technology, namely aerial, which is independent of field conditions.

Every insecticide is different. Even though the mode of action may be similar some are better as contact, others are better as oral insecticides. This is best exemplified by the use of Malathion for the control of 5th instar grasshoppers. In a comparison of droplet size and the number of droplets per cm^2 it is clear that the chemical works best as a contact control agent. In fact, at the recommended rate approximately 3 hoppers per cm^2 would be killed by contact whereas orally, the total amount of chemical in a cm^2 would be required to kill one grasshopper. Detailed consideration of droplet size vs. efficacy could result in a reduction in the amount of active incredient required for adequate pest control and for increased environmental protection.

METHODS, EQUIPMENT, AND TECHNIQUES

This area is well in place. World methods and techniques can be adapted to the Canadian scene and modified to the individual researcher's demands. The proper equipment is probably in place, but in no systematic order.

There is no one single recommendation for aerial application of insecticides. Because of the many factors which effect insect control with chemicals, applicators should be encouraged to 'tailor their application' to the specific situation. This approach need not be complex. However, considerable research is needed to establish the best combination of physical and chemical alternatives with agricultural and environmental concerns in mind.

ASSESSMENT OF BENEFITS

There are two major benefits of aerial application. The first is the speed of operation which allows large area insect control in a relatively short time. Aerial applicators can maximize the number of hectares sprayed compared to ground applicators within the same time. The second is application during, or over, unfavorable field conditions when fields are wet, or rough ground application is impossible. In both situations, fast-feeding insect pests could inflict heavy damage before the proper ground application could be achieved

Farm management today is generally professional and the operation is accomplished with a minimum of personnel; therefore, consideration must be given by the manager to the safety of his personnel in handling the 'toxic' chemicals as well as the cost of his ground application as compared to contracted aerial application. Economic considerations are not limited to the actions of a specific job, but must include the depreciation, operation, and maintenance costs for the farmers equipment. It must be remembered that the insect pest situation in prairie agriculture does not generally require multiple applications in the same growing season and therefore owning good ground equipment may not be advantageous. For the reasons outlined above, it is clear that the agriculture industry will make increased use of aircraft in pest control. The amplitude of this increase will be dependent on the success of research to decrease the negative environment implications of aerial application (i.e., the significantly higher potential drift).

THE FUTURE

The major requirements and the need for insect control have been outlined. The technology is in place on the world wide scene. However, there is no clear and systematic approach in Canada to applied research on aerial application, especially as it applies to insect control in prairie agriculture. This is not to say that we do not have scientists and agencies in Canada who have established projects considering some aspect of aerial application. Within the federal government, the National Research Council (National Aeronautics Establishment), Department of Defense (Defense Research Establishments), and Agriculture Canada (Research Branch) have the personnel who are active in research areas of interest. However, the coordination of these individuals is not in place.

There are other agencies which are involved or who could play a role in establishing the "Future Role of Aviation in Agriculture". These agencies would include the Saskatchewan Research Council, the Prairie Agriculture Machinery Institute, and the various universities on the prairies.

It is important to note that in all instances aerial application may not be superior to ground application. What is needed are research programs which outline and integrate the best aspects of both aerial and ground application techniques. There is no reason why both application techniques cannot be investigated by a coordinated multidisciplinary team. This approach would undoubtedly be the most effective and economical.

TEAM RESEARCH APPROACHES

There are various approaches to the establishment of an integrated multidisciplinary team to investigate aerial application of pesticides in the agricultural domain. The following discussions are intended to outline the mechanism and should not be considered complete or exhaustive. The views expressed are personal and do not reflect any policy of Agriculture Canada.

There are many agencies and responsibility centres which could play an active role.

Three possible ways of establishing a concerted impulse for research and development in aerial application include:

1. A single complete/total unit
2. An interdepartmental unit with single managerial accountability
3. An interdepartmental unit with a research coordinator.

The concept of a total unit is unquestionably the best alternative in the establishment of a strong multidisciplinary research team, especially for accountability. However, it is certainly the most expensive and initially may be the least practical when the location of present resources (personnel and equipment) are considered. Without a doubt, the centre for physical research in the government lies in Ottawa with the National Aeronautical Establishment. But, the centre for biological research lies within Agriculture Canada outside Ottawa. When one considers where the bulk of agricultural aerial application is at present and the potential for its growth, it is clear that the prairies would top the list. With this in mind, certainly the other two possibilities for team development could have distinct advantages of their own.

The single management concept encompasses the concept of a single management authority while the research personnel would remain at their present locations or be grouped into research and development centres but remain within their respective departments. Such a scheme ensures line accountability and funding but takes advantage of the specific discipline centres working in collaboration and along with other members of their discipline or with members of associated disciplines. This would avoid possible isolationary effects of a single multidisciplinary group which could not benefit from the day to day contact with collegues working on related problems.

The single management system has the advantages of both the 'Total Unit' concept and the 'Coordinator' concept.

The third approach, under the normal arrangements of cooperative research, is the least desirable because of the potential need for individual researchers to substantiate their projects and expenditures to separate managers. It is conceivable that at some time a piece of research may not receive priority at a particular establishment and thereby become a weak or even a missing link in the overall program. This could be disruptive to the interdepartmental program objectives and may limit other researchers in the group.

However, this could be a more viable alternative with long-term participation/secondment and funding. This type of commitment would surely go a long way towards the ultimate successful integration of personnel and resources. This may also be more easily accommodated by setting up several 'centres of excellence' or research and development centres for application studies.

SUMMARY

Through this paper, some of the major requirements for insect control at the target have been summarized. In addition, specific points for constructive discussion on the future direction for multidisciplinary research on aerial application technology for insect control on the prairies have been outlined. Certainly many areas of this research would have important implications for the application of any agricultural chemical. Ultimately, it will lead to reduced food production costs, increased crop yields, and a reduced impact of agricultural chemicals on the environment.

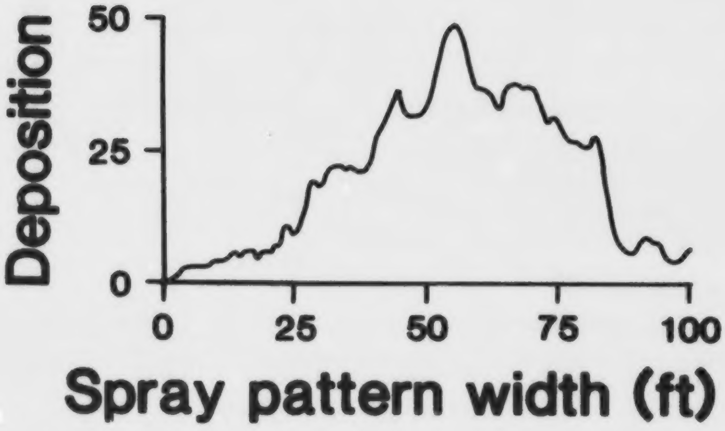


Figure 1. Spray deposition pattern of an agricultural spray plane. The curve represents the mean of three separate passes using a water and dye mixture.

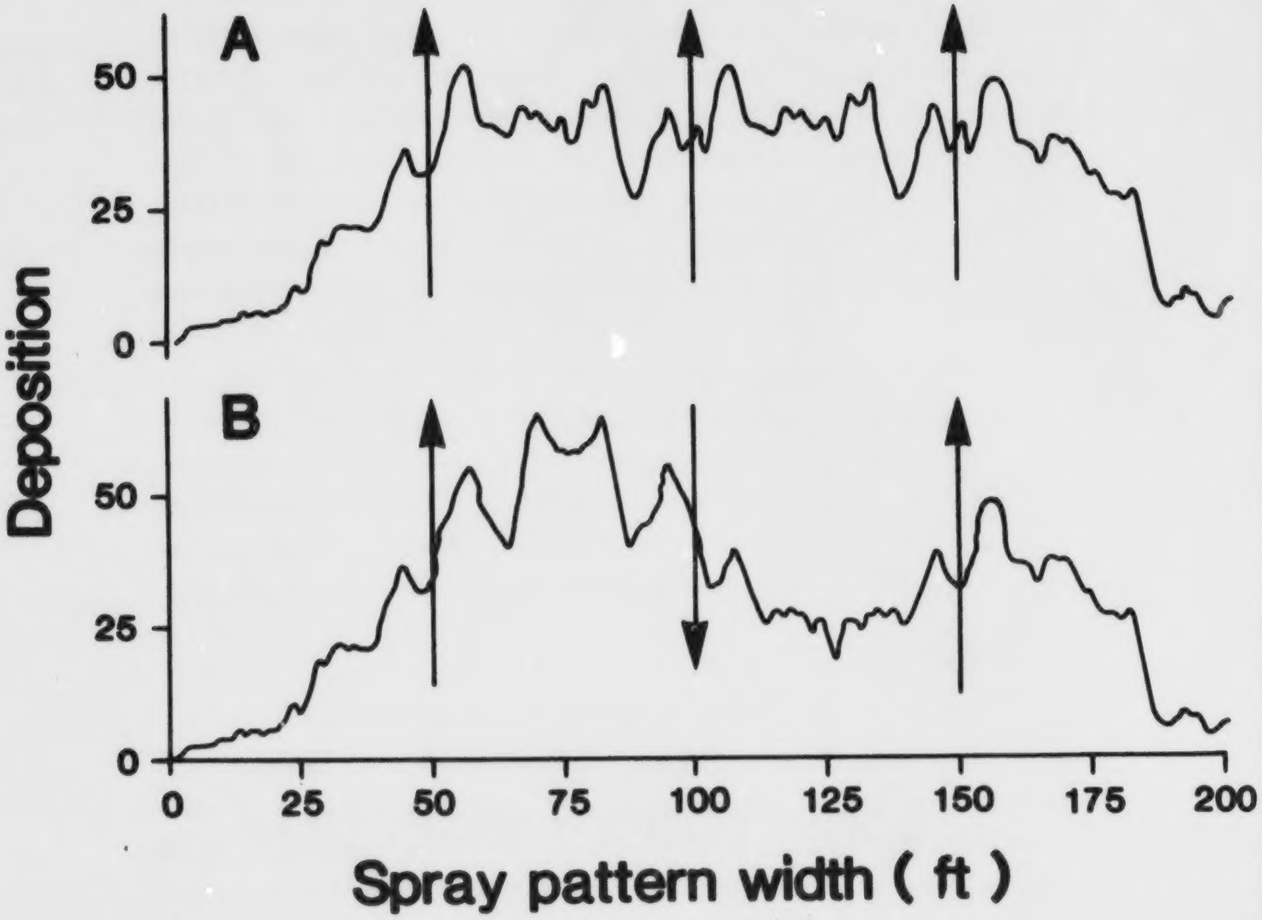


Figure 2. Computer simulation of spray deposition patterns based on the results of the mean of the three passes in Fig. 1. The top graph (2A) represents a 'race-track' flight pattern and the bottom (2B) represents an 'in-out' pattern.

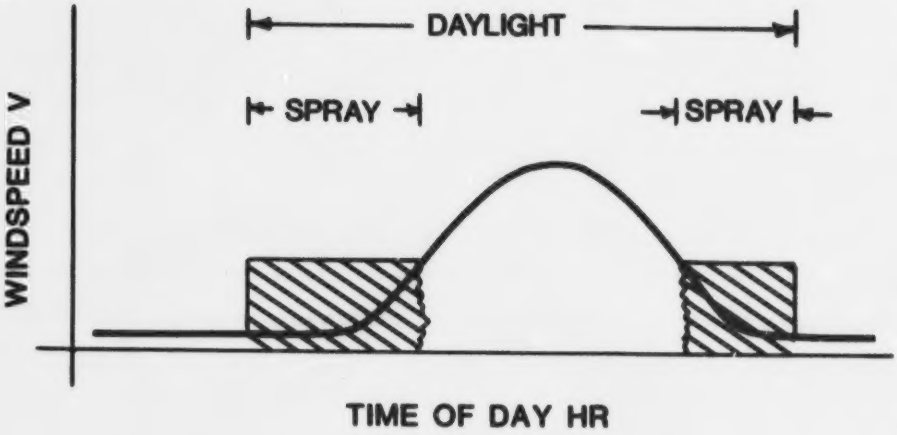
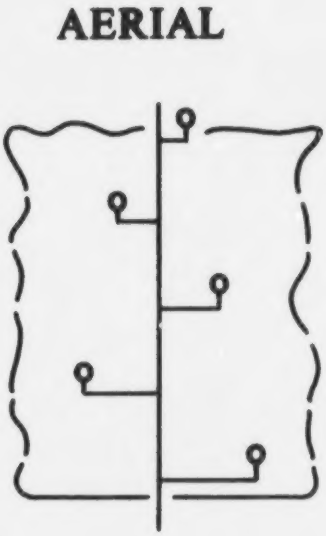

DAYLIGHT
SPRAY
SPRAY
WINDSPEED V
TIME OF DAY HR

Figure 3. A typical wind velocity (v) profile related to daylength (HR) and showing the normal periods when conditions are suitable for spraying.



DEPTH (cm)	PENETRATION (% total) BARLEY	ALFALFA
0	58	43
15	26	27
30	8	17
45	7	8
60	–	5

Figure 4. Percent canopy penetration in barley and alfalfa crops of insecticide sprays applied by aircraft.

Paper No. III-C

ADVANCES IN GROUND RIG SPRAY APPLICATION METHODS

W.B. Reed
Research Officer
Department of Agricultural Engineering
University of Saskatchewan
Saskatoon, Saskatchewan S7N 0W0

ABSTRACT

The use of field spraying as a method of weed control in western Canada is now approaching the end of the fourth decade or about half the farming period in a major portion of the area. The area treated continues to increase on an enlarging variety of crops with the number of pesticides available increasing from a few in the 1940's to over 100 formulae combinations at present.

Selective herbicides, different formulations, concern for effects on non-tolerant crops and higher costs have generated the need for greater application precision. These factors have influenced the design of sprayers, their components and operation.

Hydraulic nozzles of various design and size have been used to accommodate the initially relatively low volume spraying and slow travel speeds up to the larger sizes required to meet the higher volumes for reduced spray drift and higher travel speeds.

Sprayers have also been developed to meet these requirements with operator convenience and monitoring becoming important aspects for optimum application. Synthetic materials have drastically altered the construction and appearance of sprayers.

A trend towards reduced volume application because of limited availability of good quality water is evident. Spray drift is of more concern with low volume spraying and some sprayers are now designed to reduce drift. Rotary atomizers in lieu of hydraulic nozzles for controlled droplet size application and boom shrouds are used for spray drift control. Proposed innovative changes to reduce spraying time, to enable spraying safely under windy conditions, to avoid mixing of chemicals in the sprayer tank, and to automate the application rate are not far away.

INTRODUCTION

The changes in ground rig sprayers during the past 20 years have been many, with perhaps most changes taking place within the last 10 years. The term "ground rig sprayers", for the purpose of this paper refers to sprayers operating in open field areas as opposed to sprayers used for row crop or orchard applications. These ground rig sprayers may be trailer type, implement mounted, truck mounted or on any self-propelled chassis. There are, of course, many special versions and uses for sprayers in the application of pesticides, such as on road and railroad right of ways and many other locations not accessible with the "ground rig sprayers" considered here. This approach considerably narrows the scope of discussion and provides a simpler picture of the advances made during the past 20 years.

The changes that have been made and are forthcoming will be discussed by reference to discrete components of a sprayer rather than looking at sprayers as entire units. Rather than starting at the pesticide container tank of the sprayer the discussion begins at the point of the sprayer where the emitted pesticide leaves the sprayer and begins to travel to the target. This point, of course, is the spray nozzle in its various forms. Following that, will be the parts associated with the nozzle, plumbing components, chassis, controls and other parts now used to assist in the sprayer operation. The emission point on the sprayer, of the pesticide with its particular spectrum of spray droplets, is the "business" end of the sprayer since these droplets are required to interact with the target if there is to be effective application.

"Effective application" has been defined by Dr. E.C. Hislop (1983) of the Long Ashton Research Station, University of Bristol, as: "application techniques of pesticides applied to crops with the object of achieving a desired biological result." He states further that "effective applications are only efficient, however, if: (i) the total cost of all pesticide inputs is exceeded by the increased value of the end product; (ii) there are no adverse side effects of the use of the pesticide such as environmental contamination; and (iii) the full biological potential for a given dose of pesticide has been realized - i.e., wasteage is minimized."

The extent to which pesticide application is effective and efficient may not be known, but their use is growing and it must be assumed that effective application is generally obtained; the level of efficiency is less easily determined.

SPRAYER COMPONENTS

Nozzles: The term nozzle as related to sprayers is defined as the device which produces spray droplets. Other devices for applying pesticides such as rollers or wicks are not included in this definition although they are used for the same purpose.

There have been changes, during the past 20 years, to the nozzles used on ground rig sprayers. The most widespread change has been the increase in size of the flat fan nozzle to permit application of higher volumes per area at higher travel speeds. Application volumes presently recommended, generally are 100 litres per hectare instead of 40 to 50 litres per hectare. Travel speeds now range from 8-30 km/h rather than the 6-10 km/h of 20 years ago.

An increase in nozzle spacing is used on some sprayers, such as floaters where nozzle spacing is 3 times greater than on the earlier ground rig sprayers.

Another important change has been the change from 65° spray angle nozzles to an 80° spray angle on the flat fan tips. There is now interest in 110° spray angle nozzle tips. There are two reasons for the change, (1) a lower boom height is possible for lessening drift potential and (2) the wider angle nozzles generally have a more uniform spray distribution pattern.

The material from which nozzles are made has changed. Stainless steel with its resistance to corrosion and wear is widely used instead of brass. Other materials are also available and used; these include nylon, ceramic and other manufactured materials. Wear resistance, (Bode, L.E., et. al., 1984) distribution patterns and cost are important factors in nozzle material selection.

A variety of nozzle types have been available which produce hollow or solid cone patterns, including Raindrop nozzles. Flooding jet nozzles are also used. In addition there are flat fan nozzles designed to operate with a pressure as low as 100 kPa through to the normal pressure of 280 kPa.

Much of the change to nozzles has been with the objective of reducing spray drift (Maybank et. al., 1976). Larger size nozzles produce large sized drops, greater spray angles permit lower operating height, and nozzle designs such as the Raindrop nozzle also produce large droplets, as do low operating pressures, which all result in lower drift potential.

It is well understood that with hydraulic spray nozzles a wide spectrum of droplets is produced, including a fraction in a size which drift readily. To avoid the production of these small droplets and reduce drift, has been the aim of many researchers. The efforts have resulted in the development of the "controlled droplet applicator" or CDA (McKinley & Glen, 1971; Bals, 1978).

The CDA units are various versions of spinning discs which fling the liquid from discs of various configurations and diameter. The Herbi, Micromax (Grier et. al., 1981), Ulva, Rota-mizer, Technoma and multiple disc units are some that are in use for the production of controlled droplet size sprays.

The CDA units are low volume applicators with the potential of reducing or increasing spray drift since the rotating speed determines droplet size. Their use is increasing, probably because of the low volume application possible, with reduced spray drift.

The change in application volumes from a low of 40 to 50 litres per hectare to 100 or more litres/hectare now appears to be reversing with a trend toward much lower application volumes of perhaps 15 to 30 liters/hectare. Another characteristic of CDA units is that liquid pump pressures need not be high since pressure change does not affect droplet sizes as is the case with hydraulic nozzles. The units are however more costly and mechanically complex than the passive hydraulic nozzle. There is some evidence that canopy penetration is less with CDA sprayers due to lower droplet velocity and lesser control for directing the droplets downward to the canopy to reach weeds within the crop canopy (Kiem, 1982).

Another concept of nozzle design is appearing; those that utilize air flow to assist in droplet formation. The principle is not new, having been used in orchard sprayers, but some of the devices are new to the field sprayer. Their performance has not been evaluated by weed researchers.

Electro-static charging of spray droplets (Coffee, 1981) has received much attention, but need only to be mentioned here since the technique is very much in the experimental stage at present.

In conclusion, there is a trend toward lower volume application, with both controlled droplet applicators and hydraulic nozzles. The reason is the cost of hauling water and the shortage of good quality water.

Nozzles Holders: The holders for nozzles have changed in design and material. The use of plastic parts with diaphragm check valves incorporated instead of ball check valves along with nozzle tip alignment features, and where the nozzle tip can be removed without wrenches is very convenient. Color coding of nozzles or holders prevent mixing nozzles of different sizes.

Nozzle Booms & Support: Sprayer booms or sprayer width have increased from 10 metres to nearly 40 metres. Improvements have been made to provide easy height adjustment. Wheels are arranged to provide a stable support, with some having springs and shock absorbers to prevent boom bounce.

The material for the boom pipe may now be aluminum, galvanized steel, stainless steel or PVC material to accommodate the various chemicals. Some sprayers have two sets of boom pipes to permit quick changes to different sizes of nozzles.

Plumbing: Of importance to proper spraying has been the upgrading of the plumbing system components (Reed, 1974; Saskatchewan Agriculture, 1983, Alberta Agriculture) to accommodate the higher volume application, the greater width of sprayers and the convenience of covering large acreages without refilling the sprayer tank. Pipes, hoses, filters, valves and other fittings have increased in size to avoid pressure drops in the system. Synthetic materials are commonly used.

Pump size has increased to provide the flow needed for the nozzles and for tank agitation. The type of pump used has changed from small gear or roller pumps to larger roller, centrifugal, diaphragm or piston pumps. While most pumps are tractor power take off (P.T.O.) driven, some are hydraulically driven, although piston pumps are likely to be ground wheel driven to allow control of application rate independent of travel speed.

Tanks for sprayers are perhaps the most obvious change to sprayers. The tank size has increased from about 600 litres to over 3500 litres on some large spray rigs. The material for tank construction may now be aluminum, galvanized steel, stainless steel, fibreglass or polyethylene. Provision for easier filling, emptying, cleaning, adding and mixing of chemicals with the water is included through the use of a low profile and well designed tanks.

Undercarriage: The undercarriages of ground rig sprayers now come in a wide variety as compared to the early tractor mounted and trailer type sprayers. The trailer type is much enlarged with large and often tandem wheels supporting a walking beam. Self propelled sprayers come in a variety of forms, from a light weight chassis such as the Spray-coupe to the very large units (floaters) equipped with large low pressure tires. Trucks are often employed for carrying a sprayer. Many of the changes have been incorporated to permit high travel speeds in the field and on the highway to speed up the spraying operation. Some machines incorporate hydraulics and mechanisms to fold the booms alongside the sprayer for transport or storage.

Controls: A very apparent change in sprayers has been the addition of numerous control and monitoring features. The simple on-off valves have been succeeded by the 3-section boom control valve or directo-valves. These have been followed by electric solenoid valves for controlling flow from a remote location. The hand adjusted pressure regulator can now be replaced with electrically controlled regulators for remote control purposes. Further to these remote control devices are electronic systems to control application rate and monitor other aspects of the sprayer operation.

Automatic sprayer control systems (PAMI Evaluation Reports, 1982) are able to measure and indicate application rate, travel speed, total volume pumped, the area sprayed, the work rate, distance travelled; in either metric (SI) or Imperial units. In addition the controller automatically maintains the application at a preset rate within certain limits of travel speeds.

OTHER DEVELOPMENTS

The changes to ground rig sprayers are not complete, because changes are constantly being made.

Chemical Injection: The introduction of unmixed chemical metering and injection into the sprayer line rather than prior mixing in the sprayer tank will be welcomed by users if it is done accurately. Such a system has the possibility of applying more than one chemical, one of which can be used for spot treatment of weeds not found over the whole field. The advantage of having only water in the tank and having no mixed chemical remaining after a field is finished is attractive.

Spray Drift: Recognition of spray drift problems which damage susceptible crops and waste chemicals is not new and has been of much concern. Many of the changes to sprayers already described have been made because of the spray drift potential with sprayers of 20 years ago, i.e. low volume application.

The present desire to reduce volume of application brings with it again, the problem of spray drift. The development of rotary atomizers with controlled droplet size along with low volume application was one answer to the spray drift problem. Another approach has been to confine the spray drift within a shroud surrounding the spray boom and nozzle assemblies.

An attempt of several years ago to control spray drift with an air cushioned spray boom (Maybank et. al., 1979) was successful with regard to reducing drift, but technical problems with the shroud were either not overcome or there were other reasons that it was not developed.

The idea though has not been forgotten and at least one boom shroud is on the market. Others are in the development stage and may result in significant changes in the appearance, construction and operation of ground rig sprayers. The use of such devices on the efficacy of chemicals and thus the rate that they must be applied is not known, but if successful such devices will lengthen the spraying time available, since ambient wind will be less of a factor. These devices combined with low volume sprayers will affect the sprayer design and changes will continue.

CONCLUSIONS

The changes to ground rig sprayers as outlined have been many and are beneficial in meeting the requirements of today's agriculture, but what have been the advances in application methods? Advances imply that progress is made toward a goal or objective. Returning to the beginning of this paper it is evident that the "business" end of the sprayer, ie. the nozzles, has not changed dramatically. Certainly there have been improvements made to sprayer nozzles and to the boom assemblies which support them to permit more uniform application of chemicals with less spray drift potential. Most sprayers in use today still rely on hydraulic nozzles to apply the pesticides to weeds, insects or fungi. Although there are some sprayers equipped with controlled droplet size applicators, they are not in widespread use; therefore hydraulic nozzles still predominate.

If the goal has been to improve the application method in order to achieve effective and efficient application, there has not been a major advancement in the three areas outlined by Hislop (1983). Cost of chemicals for crop spraying is a major input in crop production, and net returns or effective application must be there; for surely thousands of farmers are not wrong. Whether the returns are greater than 20 years ago is more difficult to ascertain, but spraying continues to increase.

There is no doubt that the cost of sprayers has changed. Twenty years ago a typical trailer ground rig sprayer, 13 metres in width was listed at about $500. Today, in 1984, a typical sprayer now about 25 metres wide, probably lists at over $7,000. Self-propelled sprayers cost from $20,000 to over $70,000. Investments of these amounts require that the annual area covered by a sprayer be much greater, and this is enabled by the increased width, higher travel speeds and lower application volumes. The number of days suitable for spraying has not changed with wind frequently limiting the time available. This has resulted in proposed sprayer changes to control spray drift so that the spraying period can be extended.

Adverse side effects of the sprayer, as far as is known, have not increased nor will they likely increase if spray drift is controlled. The increased amount of spraying though may have an effect on enviromental contamination which should not be charged to the advances or changes in application methods, ie. the sprayer developments.

The third area, referring to realizing the biological potential for a given dose of pesticide (minimum waste), has perhaps seen only slight progress towards this goal. Less spray drift has been helpful in reaching the goal as has more uniform application to the field. However, spraying is still a "blanket" approach; cover everything to get the pest in question. Only a small portion of the chemical applied is needed to kill weeds. Much of the chemical is intercepted by the crop which does not need spraying, and a major portion of it goes directly to the ground. In this respect there has not been much progress in the application methods.

Controlled droplet applicators may have value if certain droplet sizes are more effective in carrying more of the chemical to the target. If better drift control is achieved with lower volume application than with the wide droplet size spectrum of hydraulic nozzles, there is advancement toward the goal. Other devices to control drift from hydraulic nozzles can be useful in the same way, particularly if smaller droplets can carry more chemical to the target.

In conclusion; there have been many changes to ground rig sprayers that represent advances in terms of operation and in timeliness of operation. The advances in the application methods have not been as noticeable nor to the same extent, since most sprayers are still equipped with hydraulic nozzles operating with the same principle of producing a wide spectrum of droplet sizes applied in a blanket fashion. The challenge is still before us to make more advances toward the goal of decreasing chemical use.

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Paper No. IV-A

AIR REGULATIONS

J.F. Mew
Manager
Airworthiness Manual Project Group
Transport Canada
Tower B, Place de Ville
Ottawa, Ontario
K1A 0N8

ABSTRACT

The legislation and regulations governing the aeronautical control of Canadian licenced aircraft engaged in agricultural operations are examined.

Agricultural aircraft form part of a group of aircraft which are engaged in some form of special operation, which results in a non-standard type of airworthiness certificate and the imposition of operational limitations. The past practice in Canada has been to impose fairly strict airworthiness standards on the aircraft and relatively modest operational limitations. The United States practice has tended towards the opposite approach.

The changes in philosophy on Canadian airworthiness standards for agricultural aircraft in the past two decades are presented, and comparisons are made with the U.S. position. Based on the recommendations of the Dubin Commission of Inquiry on Aviation Safety, Canada is now moving closer to the U.S. standards for airworthiness. An attempt is made to assess the impact of this decision on future airworthiness and operational standards for agricultural aircraft.

AIR REGULATIONS

Legislative Background

The responsibility for the control of aeronautics in Canada rests with the Federal government and is administered by the Minister of Transport under the authority of the Aeronautics Act. The Act, which is typical of most federal legislation, provides broad enabling powers for the Minister to make regulations and orders, which are contained in the Air Regulations and Air Navigation Orders.

The Air Regulations and Air Navigation Orders have the force of law, but from a technical point of view remain fairly broad in context. Accordingly, there is another tier of documents which describes in more detail what is required to obtain flight authority for an aircraft, the authority for piloting and maintaining aircraft, and authority for conducting a commercial air service, etc.

Regulation of Standard Category Aircraft

Before considering the role of aircraft, such as agricultural aircraft, which are engaged in special operation, it is appropriate to outline the procedures which are in place to regulate the flight of standard category aircraft in Canada. There are essentially three elements which need to be addressed, namely the aircraft, the pilot and the operation.

Airworthiness Requirements

With regard to the aircraft, Canada has, in common with most other aviation minded states, adopted the procedures recommended by the International Civil Aviation Organisation (ICAO). This requires the promulgation of standards of airworthiness governing the aircraft type design, which include the aircraft performance, handling and stability, structural integrity, powerplant and fuel system, flight and electrical systems, detail design, as well as flight manuals and placards detailing the aircraft limitations.

Until 1982, Canada had not adopted any specific set of standards, but recognised, for the purpose of granting an aircraft type approval, either the United States or United Kingdom Standards. In 1982, we legally adopted by reference the U.S. Federal Aviation Requirements as Canadian standards. These include FAR Part 23 for normal category aeroplanes and FAR Part 25 for transport category aeroplanes as well as FAR Parts 27 and 29 for normal and transport category rotorcraft, respectively. Provision has been made for the adoption of additional airworthiness requirements in each of these standards to accommodate requirements resulting from unique Canadian experiences or environmental conditions.

Aircraft shown to conform in manufacture to an approved type design which meets one of the above standards of airworthiness are issued with a Certificate of Airworthiness which is the legal authority permitting the aircraft to fly.

Requirements for Pilot License

With regard to the flight of the aircraft, the pilot is required to have a valid license issued by the Department of Transport. The type of licence and thus the experience required, in terms of flying hours and the aircraft type rating, depends on the intended purpose of the flying.

A private pilot licence, which is required for non commercial flying, is obtained after the successful completion of written examinations and a total of 35 hours flight time, of which at least 12 hours are solo flying. A commercial pilot licence, requiring a total of 150 hours flight time, of which at least 100 hours must be pilot in command time, will permit the flying for commercial operations as pilot in command of aeroplanes having a maximum take off weight of 12 500 lb or less. This aircraft grouping covers most of the agricultural aircraft types operating in Canada.

These flight times are the minimum required for the issue of a licence and do not consider the training and experience to obtain additional endorsements and priviledges, for example, for a night flying rating, seaplane rating or multi-engine aircraft rating.

At this time, the national average flight time of applicants for a private pilot licence is approximately 53 hours.

Requirements for Commercial Operation

Finally, with respect to commercial flying operations, there is both an economic and safety licencing requirement. Canada has not yet adopted the United States deregulation approach regarding the economic freedom to enter and leave commercial aviation. Therefore any person or company engaged in commercial flying operations in Canada is required to obtain a licence from the Canadian Transport Commission (CTC) which is an independent economic regulatory body reporting to the Minister of Transport. There are a number of different classes of operation, the one relating to speciality flying such as agricultural operations being Class 7. Typically the CTC will not permit a new entry into a class where there are already a number of operators and the market does not appear to be growing. Requests for new entries are published with the right of appeal from existing licenced operators and if warranted, public hearings are held to obtain a broader spectrum of opinion.

The safety licencing is established by an Operating Certificate issued by the Ministry of Transport. This requires the demonstration of adequate human and material resources for pilot training and flight operations as well as the maintenance of the aircraft.

Pressures for Changes to Regulations

In general, the pressures for change to any of the regulations governing aeronautics come from a variety of sources. It is a sad fact of life that although aviation has matured enormously within the various modes of transport, it is still perceived by the public at large, the media and quite often by our political masters, as an inherently risky undertaking. Accordingly, any aircraft accident or significant incident will almost inevitably create a demand for the imposition of new regulations.

In a more systematic, and less emotional manner, the findings of the causes of most accidents and incidents, analysed by such independent bodies as the U.S. National Transportation Safety Board and the newly formed Canadian Aviation Safety Board, frequently result in recommendations for changes to regulations.

Occasionally, however, public and political pressure will result in a major external review of safety regulation. This occured in Canada in 1979 with the formation of the Commission of Inquiry on Aviation Safety presided over by Justice C.L. Dubin of the Ontario Court of Appeal. Justice Dubin's Inquiry resulted in a report containing 247 recommendations which, in implementation, are having a very significant effect on the regulation of aeronautics.

A surprising low key pressure for change comes from the various associations representing all the various facets of aviation. While one should not in any way detract from their many useful contributions to regulatory change, often in friendly collaboration with the regulatory body, it seems that the role of these organisations is more often to oppose rather than propose changes to regulation.

Examples of Pressure for Change

Two events illustrate the role of pressure groups in seeking to obtain changes to regulations with respect to the operation and piloting of agricultural aircraft.

The first occured a number of years ago, when requests by flying farmers led to the introduction of Air Navigation Order Series VII N°1, Private Aircraft Exemption Order, which permitted a farmer to conduct aerial spraying or dusting operations within a

25 mile radius from the centre of his farm for hire or reward, without requiring either an operating certificate or the use of a commercially registered aircraft.

The only requirements are that if the farmer is pilot in command, he requires a minimum of 150 hours flight time, including not less than 25 hours flight time on the type of aircraft being used. If the aircraft is flown by anyone other than the farmer, the pilot must hold a commercial pilot licence.

The second request for a change occured as the result of two federal-provincial conferences on agricultural and forestry aviation activities, organised by Peter Southwell, the first chairman of the NRC Associate Committee on Agricultural and Forestry Aviation.

The conference recommended that all pilots engaged in aerial application activities should be provincially licenced for the handling and distribution of chemicals and their pilot licences should be endorsed for aerial application work. This latter recommendation required successful graduation from a special training school for aerial application activity in order to obtain a licence endorsement.

The response by the Department of Transport was that there was no requirement for such a licence endorsement. There are no endorsements, per se, for specific flying activities and it is more appropriate to place the requirement for training on the operator as a condition for the issue of an Operating Certificate.

Coincident with the Dubin Commission of Inquiry and reinforced by the Commission recommendations, there has been a major review of the Aeronautics Act and subordinate Air Regulations and Air Navigation Orders. As a result of this review, the proposed revisions to the commercial Air Service regulations will require specific training and recurring training for the pilots engaged in aerial application operations.

Since, as indicated earlier, flying farmers are excluded from compliance with certain regulations for commercial operators, it will require a close review of accident statistics to determine whether a broader application of the special training requirements would be justified.

Airworthiness Requirements for Agricultural Aircraft

The concluding section of this paper will address in more detail the airworthiness aspects of agricultural aviation. The Department of Transport approach to this subject has undergone several changes over the past two decades and will very likely change in the coming year.

Early Requirements

Initially, the aircraft used for agricultural activities were either types approved to normal category airworthiness standards, which had been modified for agricultural work, or they were ex-military aircraft.

These aircraft could be approved for agricultural activities by demonstrating compliance with airworthiness requirements specified in the Department's Engineering and Inspection Manual (E and I). The Manual, by now a somewhat venerable document, is authorized by the Air Regulations and contains a number of standards and procedures relating to the airworthiness of aeronautical products.

The E and I Manual assumed that the normal category maximum take off weight would need to be increased by up to 20% in order to accommodate a useful payload for the agricultural application. Requirements relating to aircraft performance, handling, including stalls, and flight manual data are included in the E & I Manual.

Aircraft which were shown to comply with these requirements were authorized to fly either with a Flight Permit (for privately registered aircraft) or with a restricted Certificate of

Airworthiness. This form of flight authority effectively limited to role of the aircraft to agricultural activities (e.g. it would specify single pilot operation with no passengers) but did not significantly restrict the geographical area in which the aircraft could fly.

The U.S. Approach

By the late 1960's a trend was developing away from modified normal category aircraft towards specially designed agricultural aircraft. In the United States, the regulatory position of the Federal Aviation Administration permitted the designer of the agricultural aircraft to use quite a degree of latitude with his design. The designer was required to utilise the normal category airworthiness standards where appropriate. However, those requirements which seemed to the designer to be inappropriate may be waived by the FAA and in their place airworthiness criteria are set out in published advisory material. These criteria are not as specific as the regulations and in many instances are intended as good design practices. Amongst other things, the use of the criteria permits operation in an overload condition and relaxes certain of the performance and handling regulations.

The compensations in the total U.S. regulatory System, which provide for an overall acceptable level of safety, lie in the operational regulations contained in FAR part 91, Air Traffic and General Operating Rules, and FAR Part 137, Agricultural Aircraft Operations.

In general, Part 91 contains limitations applicable to all restricted category aircraft engaged in special purpose operations, while Part 137 specifies the conditions with which an agricultural operator must comply to operate in areas, or under conditions, that are not allowed under Part 91. There is thus a considerable degree of precision in the U.S. operating restrictions which prescribe limitations on the use and operation of the aircraft in an agricultural role.

The Need for Change

As the design of aircraft changed to special-purpose agricultural aircraft, it became apparent that the E and I Manual requirements were not adequate and a decision was made to develop new requirements. In the absence of Canadian operating requirements as specific as FAR Parts 91 and 137, it was decided to produce detailed airworthiness standards for agricultural aircraft.

The United Kingdom and Australia requirements were reviewed and a draft Canadian standard was developed. It consisted of FAR Part 23, standards for normal Category aircraft, with a number of amendments, some of which were more rigorous and some of which relaxed or waived specific FAR 23 requirements.

In retrospect, it is possible to question the wisdom of the step we proposed to take. As a regulatory authority, the Canadian Department of Transport had no great experience in developing a detailed airworthiness standard. Indeed in the whole Western World only the U.S. Federal Aviation Administration and the U.K. Civil Aviation Authority had the technical resources and the historical body of data which permitted the development and maintenance of a comprehensive code. Furthermore, the size of the agricultural aircraft operation in Canada was very small and did not result in the development of a meaningful analysis of the limited accident and incident data available.

Industry Response

The draft standard was duly developed and submitted for comment to the various Canadian aviation associations which had a special interest in this subject. Predictably, the response was not one of enthusiastic support. The small Canadian operating industry relied entirely on imported aircraft, there being no domestic production of agricultural aircraft. Any increase in Canadian standards, not recognised and introduced in other countries, would result in more expensive aircraft modified for the Canadian market. The associations and particularly ACAFA made the point referred to above that there did not appear to be any significant body of accident data which would justify the promulgation of these standards.

Later Developments

A hiatus then occured, which was not entirely due to the reaction by industry to the proposed standards. The Airworthiness Branch of DOT was becoming preoccupied with the interpretation of standards in the domestic type approval of certain transport category aircraft and we were embarking on an elaborate review of all of our airworthiness requirements. These activities consumed the limited technical resources available to the Branch. In addition, the downturn in the economy had drastically reduced both the total number of agricultural aircraft being produced and also the number of new types being imported into Canada.

Current Approach

Our story now moves into the present era. The recommendation of Mr. Justice Dubin was that the Canadian Airworthiness Code should be an adoption of the U.S. Federal Aviation Airworthiness and Operational Requirements amended by requirements reflecting the Canadian aviation experiences or environmental conditions. Consequently, in the most recent internal reviews conducted within the Airworthiness Branch, it has been concluded that it would be appropriate to adopt the U.S. approach to the safety control of special purpose aircraft, including agricultural aircraft.

This means, in effect, that designers will follow, where applicable the requirements of one of the adopted standards, such as FAR Part 23. Where, however, he finds particular requirements inapplicable, he will negotiate alleviations with the Department of Transport, using the FAA airworthiness criteria for agricultural aircraft as a guide.

The relaxing of airworthiness standards will require a corresponding tightening of operating limitations for special purpose aircraft. To this end we are presently reviewing the applicable sections of FAR Part 91 and the limitations of FAR Part 137.

In the interim, whilst this revised approach to agricultural aircraft is being developed, the following policy is in operation for the airworthiness approval of new agricultural aircraft types. An applicant for a type approval will be required to assess the aircraft to the applicable standard (FAR Part 23 at an appropriate amendment for a small aeroplane) and identify areas of non-compliance. The applicant must then satisfy Transport Canada that a level of safety consistent with the agricultural role can be ensured by imposing suitable limitations to contend with the areas of non-compliance.

The type of aircraft and operation which has been considered throughout the paper is the fixed wing aeroplane operating in an agricultural role under day visual flight rule conditions. Certain types of operation require night flying and this is now being reviewed, with regard to identifying additional operating limitations.

Although rotorcraft have also been employed extensively in agricultural operations, they have not been specifically referred to, as the operation can be conducted, from an airworthiness point of view, within the limitations prescribed by the standards of airworthiness for normal category rotorcraft.

CONCLUSIONS

The federal government control of aircraft exercised through the application of the Aeronautics Act and the Air Regulations impacts primarily on the airworthiness control of the aircraft, the control of the person flying the aircraft and the control of the commercial operation of the aircraft.

As a result of major attempt by the Department of Transport to overhaul both the Act and the Regulations and in response to the recommendations of the Commission of Inquiry on Aviation Safety, the regulations will impose additional initial and recurrent training requirements for pilots engaged in the commercial operation of agricultural aircraft.

There are no changes contemplated for farmers presently exempted from the commercial operation regulations for agricultural aircraft.

In the field of airworthiness, an attempt is being made to move towards the U.S. position, namely to permit non compliance with items contained in the normal category airworthiness standards, providing it can be demonstrated that an acceptable level of safety can be achieved by imposing suitable limitations on the aircraft operation.

As in all other areas of the Air Regulations and in response to another Commission recommendation, a high level of consultation is required between the regulatory body and the affected aviation associations on all proposed amendments to the requirements.

Specifically with regard to agricultural aircraft, although equally true for other categories of aircraft, the Department of Transport is concerned with working closely with other airworthiness authorities, particularly the FAA, to ensure that ther are no unique "made in Canada" requirements which will act as economic impediments to the Canadian industry. The only exception to this will be where Canadian experiences resulting from operational or environmental problems require definite action within the Canadian system and where we are unable to persuade our foreign colleagues to adopt such an amendment. Again, it should be once more emphasised that such amendments will only be put into effect after full consultation with industry associations.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the advice and assistance of his colleagues in the Airworthiness and Licencing and Certification Branches, Department of Transport. In particular, he wishes to thank his colleagues in the Airworthiness Manual Project Group, Aeronautics Act Task Force; the recent proposals contained in the paper have been developed by the Project Group during their review of airworthiness requirements for agricultural aircraft.

Since the author was unable to be present at the ACAFA Symposium, he wishes to express his gratitude to Mr. Maher Khouzam, who kindly consented to read the paper.

Paper No. IV-B

AERIAL APPLICATION OF PESTICIDES REGULATORY ASPECTS

M.P. Stewart
Pesticides Division
Plant Health & Plant Products Directorate
Food Production & Inspection Branch
Agriculture Canada
Ottawa, Ontario
K1A 0C6

ABSTRACT

In Canada, pesticide sale and use is regulated, by Agriculture Canada, under the authority of the Pest Control Products Act. A key element to this legislation is that the onus is on the applicant to demonstrate the safety, merit and value of a pesticide prior to registration and subsequent sale and use. The registration process involves the review of efficacy data supporting the merit and value criteria and toxicological and environmental impact data respecting safety criteria. This review enables definition of appropriate directions, limitations and precautions for use to be included on the pesticide label.

Many pesticide labels do not carry instructions for aerial application. In general, the supporting data for these products was developed for the more common method of application, i.e. ground sprayers. The increase in aerial application, in recent years, has prompted many inquiries regarding regulatory interpretation of labels which are not specific with respect to mode of application. Under current interpretations, all existing commercial class products which do not contra-indicate aerial

application can be applied by air if the use does not include forest, bodies of water or residential areas. Registrants are currently being encouraged to outline appropriate use directions and precautions for aerial application on registered product labels. In addition, all labels are being reviewed for appropriateness of instruction in a label improvement program. This program may result in more specific requirements regarding application methods. For new products, applicants are expected to provide data and/or documented field experience to support directions for aerial use.

This procedure strikes a regulatory posture that is consistent with the practical realities that have developed over the years through field experience. At the same time, it addresses the need to document safety, merit and value of aerial application and to develop appropriate directions and precautions for use. More research and development into such areas as efficacy, drift, occupational exposure and environmental impact should be encouraged. This type of information is needed to support regulatory functions, to provide growers and applicators with the most current information on aerial application techniques and finally, to improve public awareness of the benefits associated with this important application technique.

INTRODUCTION

Recently, the role of aviation in agriculture is becoming more evident. Use is on the increase and an organized approach by all facets involved is seen to be the best answer to efficiently develop guidelines, data and recommendations as support for regulatory functions and to provide up-to-date technology for growers and applicators.

Prior to discussing current procedures for aerial application of pesticides and some of the information needed to support this valuable application tool, I shall briefly review the regulatory process in Canada.

In Canada there are in excess of 100 laws that have some authority over the sale, use or consequence of use of pesticides. This includes legislation adopted by federal, provincial and municipal governments. Only a few of these laws relate only to pesticides.

PESTICIDE REGULATION

Pest Control Products Act and Regulations

The principal federal law which governs sale and use of pesticides in Canada is the Pest Control Products Act (P.C.P.). Under the authority of the P.C.P., the Pesticides Division of Agriculture Canada, reviews registration applications for all pesticides intended for use in Canada.

Under the Act, a control product is defined as anything that is manufactured including devices, represented, sold or used in controlling, preventing, destroying, mitigating, attracting or repelling any pest. Thus in addition to the traditional agricultural herbicides, insecticides, fungicides, and vertebrate control products, such product classes as: disinfectants, algaecides, slimicides, wood preservatives and antimicrobial additives to paints, plastics, cements and textiles require registration.

The Act may be broken down into four major clauses:

1. No person shall manufacture, store, display, distribute or use any control product under unsafe conditions related to health and environmental quality.
2. No person may package, label or advertise any control product which could be deceptive in character, value, quantity, composition, merit or safety.

3. No person shall sell, or import any control product unless it is registered as prescribed.
4. No person shall export or convey from province to province, any control product which is not made in a registered manufacturing establishment.

The remaining elements of the Act and the Regulations are oriented to provide authority to achieve these purposes.

Data Requirements

The Evaluation Section, of the Pesticides Division, in addition to reviewing efficacy data, co-ordinates a comprehensive review of data where new standards are required; this may be a new product or a new use for an existing product. The key authority for this data requirement is Section 9 of the Regulations, which specifies that "the applicant shall provide the Minister with such information as will allow the Minister to determine the safety, merit and value of the control product".

The regulations further specify what scientific investigations are necessary for the Minister to determine, the safety, merit and value of a product.

In order to make this assessment, the following are, in general terms, typical of the data required:

1. Product label (draft).
2. Product chemistry, including information on product identity, manufacturing process, specifications, analytical methods and physical and chemical properties.
3. Toxicology data to demonstrate safety of the product for persons occupationally exposed to it when it is manufactured, stored, displayed, distributed or used.
4. Residue data on food or feed crops including analytical methodology and animal metabolism studies.
5. Environmental chemistry to demonstrate physical or chemical degradation, metabolism, mobility, field dissipatation or accummulation.

6. Environmental toxicology data to demonstrate effects on birds, mammals, fish and aquatic organisms.
7. Efficacy data to show effectiveness of the product for the intended purpose and safety of the product relative to the host plant, animal or article for which it is to be used.

Data Evaluation

Copies of the required data, submitted by the applicant to the Evaluation Section, are distributed to other government departments, which are consulted for expertise in specific areas:

1. Agriculture
2. Health and Welfare
3. Environment
4. Fisheries and Oceans.

More specifically, the advisors in Agriculture could include members from the following groups:

1. Laboratory Services Division - comment on the chemistry sections of the submission.
2. Plant Health Division - if submission is related to quarantine control.
3. Animal Pathology Division of Health and Animals Branch - if the product is for use on animals.
4. Canada Grain Commission - if the product requires a maximum residue limit for grains.
5. Research Branch - relating to efficacy, pest management control and impact.

In Health and Welfare, the following groups may be consulted:

1. The Additives and Pesticides Division of the Health Protection Branch - comments on the acceptability of toxicology and residue data relative to proposed pre-harvest intervals and residue tolerances for the purposes of the Food and Drug Act.

2. The Environmental Health Directorate - assesses occupational and public health aspects and gives advice on first aid statements, toxicological information, use of the protective equipment, health effects of residues in potable water and advice relating to precautionary symbols and product classification.

In Environment Canada, officers in the following groups may be consulted:

1. The Environmental Contaminants Branch - assesses potential for environmental contamination (product persistence/degradation) and disposal (disposal of pesticides containers, storage and disposal of unwanted pesticides and decontamination of spills).
2. Canadian Wildlife Service - comments on environmental toxicity data relating to safety of birds and mammals.
3. Forest Pest Management Institute - if the product is intended for use in forests would comment on efficacy, spray application techniques and environmental impact.

In Fisheries and Oceans Canada, the Habitat Management Branch would be consulted for aquatic toxicity and impact particularly if there was potential for the chemical to get into natural water bodies.

Product Registration

Following the review of data supporting the safety, merit and value criteria for registration, comments from all consultants are reviewed by Agriculture Canada, and if necessary additional questions or data requirements may need to be addressed by the applicant. The purpose of this extensive review enables definition of appropriate directions, limitations and precautions respecting product use on the pesticide label. The label, essentially becomes a legal document which prescribes the proper use of the product and the means whereby the product can be used safely.

AERIAL APPLICATION

Past

In the past aerial application was of little importance relative to ground application. It was used primarily in emergency situations such as insect infestations and wet field conditions. Consequently research with aerial applications was minimal in both the private and public sector.

Thus the evaluation of data supporting many older products lead to label directions, limitations and precautions based on the traditional mode of application - ground equipment. Directions typically reflected water volumes and general spray recommendations associated with, but not necessarily specific to, ground rigs.

Present

Today, as we all know aerial application of pesticides in agriculture has seen a dramatic increase, with estimates of 10-15% of the treated acreage being applied by air. Aerial application offers many advantages including:

a) timely application regardless of ground conditions
b) more effective weed control due to speedier application when optimum control conditions exist,
c) more energy and cost efficient,
d) contract spraying affords the grower more time to accommodate other activities during busy parts of the season,
e) spray coverage without equipment damage to emerged crops and to crops exceeding the height of conventional ground equipment.

These advantages coupled with the increase in use of post-emergence herbicides and expanded use of post-seeding insecticides and fungicides, are often quoted as the main reasons for this increase.

As a result of the increase in aircraft use, the Pesticides Division, has received many inquiries regarding the regulatory interpretation of labels which are silent regarding aerial application. Many older product labels do not carry directions or a contra-indication.

The current regulatory interpretation in this regard is published in a Trade Memorandum (Figure 1). All existing COMMERCIAL classified products which do not carry a contra-indication on the label may be applied by air if the uses do not include forests, bodies of water or residential areas. This interpretation is a realistic and practical approach, which reflects the long experience with established products, and practical realities of each individual use situation. Obviously, the persons on the operational site, for example the aircraft operator, crop owner, chemical company representative and provincial agriculturalists and environment personnel are in a much better position to make on site judgements regarding an unsafe condition, than are those remote from the individual circumstances and conditions involved. It is for this reason, that we feel a "no objection" posture is appropriate in areas where labels for established products are silent in respect to aerial applications.

By this regulatory interpretation we are certainly not suggesting abandonment of our interests and efforts in appropriate label directions for aerial application. Registrants of older products are being encouraged to outline appropriate use directions and precautions for aerial application. In cases where definite concerns have been expressed, these labels will carry a contra-indication. If however, practical field experience supports aerial use and other concerns (i.e. environmental impact or occupational hazards) are not evident, registrants will be in a position to amend their product label to include this use.

Registrants of new active ingredients will be required to provide data and/or documented field experience to support directions for aerial use.

Products which are contra-indicated by statements such as "apply by ground equipment only" or "do not apply by aircraft" or both, are not to be applied by air. In this situation, prohibition respecting use is found in Section 45 of the regulations, which reads "no person shall use a control product in a manner that is inconsistent with the directions or limitations respecting its use on the label." Use of a product contrary to Section 45 is deemed a use contrary to Section 3(1) of the Act (i.e. deemed to be used under unsafe conditions) and would be considered a violation.

Future

The use of aircraft in agricultural spraying operations will likely continue and may even expand. In order to support the safety, merit and value criteria associated with this valuable application technique, certain additional data will be required from applicants.

The merit and value criteria will require the support of efficacy data to demonstrate that the effectiveness of the product is maintained when compared with traditional ground application.

Experience has shown that by lowering spray volumes and droplet size to those typical of air equipment, the efficacy of some products may be reduced. This is the case for a contact herbicide like bromoxynil, which requires adequate spray coverage. Translocated herbicides such as 2,4-D, on the other hand, will not require the same coverage.

Such differences in mode of action may need further research by modifying spray volumes, nozzle placement, arrangement and number, to ensure appropriate directions for products like bromoxynil. Without such research efforts, products that have not been shown to be effective would carry limitations for aerial use.

Aerial application, should be supported by data in which comparisons have been made between ground and aerial equipment. Such side-by-side comparisons will enable evaluation with similar weed spectra and under similar environmental conditions (i.e. wind speed, air temperature etc.). Use of the research permit provisions are encouraged to make such comparisons for data development.

The safety criteria provided in the regulatory process, respects the risk or hazard to the user, bystander and the environment. Both these areas are focal points for public concern when it comes to aerial application; and have become increasingly important aspects of pesticide regulation.

Occupational risk to the user and bystander, as I have already eluded to, is reviewed by the Environmental Health Directorate of Health and Welfare Canada. The extensive toxicology requirements and review afforded a new active ingredient allows an assessment of the inherent toxicity. The degree of exposure and inherent toxicity need to be considered with aerial application as well as ground application. Thus, development of exposure models with different application equipment coupled with a compound's inherent toxicity will determine either appropriate precautions for its use or a contra-indication.

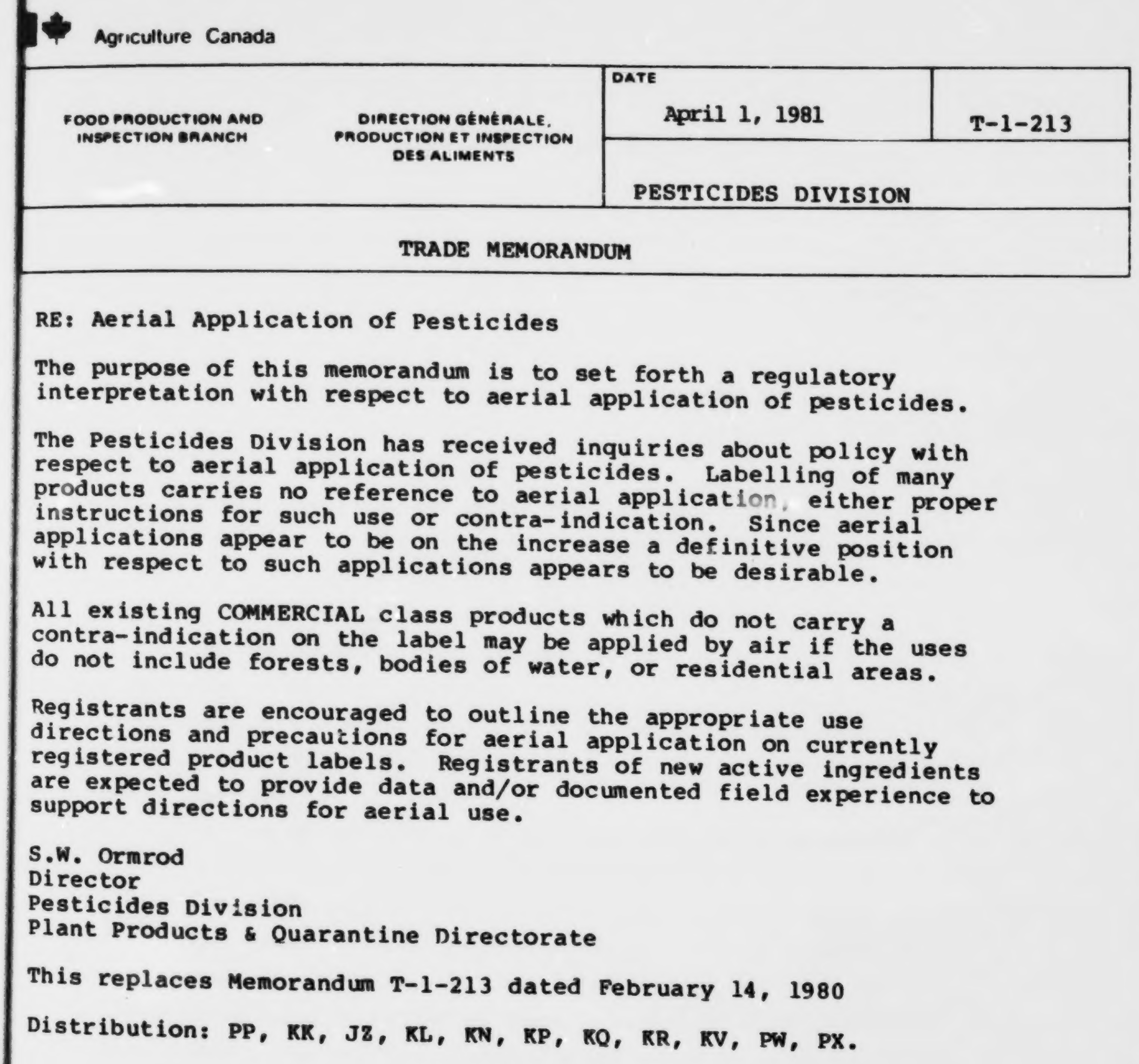
Environmental impact of pesticide application by air is a prime concern of consultants in Environment Canada and Fisheries and Oceans Canada. This concern centres around the common 10-15% drift associated with aircraft application. Properties of concern to these groups include toxicity to fish, aquatic invertebrates and wildlife, persistence in water and soil, propensity to get into water and effects on aquatic vegetation. Application techniques which increase the exposure of chemicals with such properties will undoubtedly require further testing to show that integrity of fish and wildlife habitats in sloughs, wetlands and other off-target-locations is maintained. For example, compounds such as the synthetic pyrethroids due to high fish toxicity and picloram due to its' persistence and effects in off-target sites, are not currently acceptable for aerial use in agriculture.

Research and Development Considerations

Improvement or expansion in research and development of aerial application should undoubtedly be a high priority for both provincial and federal research institutions and industry. Many suggested areas for further work will be brought forward by others, however, the following would appear to be supportive of both provincial and federal regulatory functions;

1. Reduction of potential off-target spray displacement to eliminate or reduce user and bystander exposure and environmental impact. Drift reduction potential by development [illegible] optimum environmental conditions for spraying, ne[illegible]zzle and nozzle arrangements, increases in droplet size and spray volume etc. should be considered.
2. Development of occupational exposure models through measurement of spray contact to personnel involved, directly or indirectly in the spray operation (i.e. pilot, loader, flagmen, bystander).
3. Field monitoring studies to depict secondary effects on and modification to wildlife habitats.
4. Development of a capability to relate biological significance (efficacy) with spray technology and physics (eg. spray volumes, optimum droplet size, drop density and spray concentration).
5. Development of a capability to assess efficacy of pesticides applied by aircraft on a continuing basis and to re-asses problems with aerial application of some materials like bromoxynil, to determine if sprayer modifications can accommodate safe application via air.

These areas for further research and development are needed for a number of reasons including, the support of regulatory functions, by documentation of information to support the safety, merit and value of aerial application, and to develop appropriate directions, precautions and limitations for use on product labels. In addition more research and development into efficacy, drift, occupational exposure and environmental impact should be carried out to provide growers and applicators with the most current information on aerial application techniques and finally, to address public concerns and improve public awarness of the benefits associated with this valuable application technique.



Agriculture Canada

FOOD PRODUCTION AND INSPECTION BRANCH	DIRECTION GÉNÉRALE, PRODUCTION ET INSPECTION DES ALIMENTS	DATE April 1, 1981 PESTICIDES DIVISION	T-1-213

TRADE MEMORANDUM

RE: Aerial Application of Pesticides

The purpose of this memorandum is to set forth a regulatory interpretation with respect to aerial application of pesticides.

The Pesticides Division has received inquiries about policy with respect to aerial application of pesticides. Labelling of many products carries no reference to aerial application, either proper instructions for such use or contra-indication. Since aerial applications appear to be on the increase a definitive position with respect to such applications appears to be desirable.

All existing COMMERCIAL class products which do not carry a contra-indication on the label may be applied by air if the uses do not include forests, bodies of water, or residential areas.

Registrants are encouraged to outline the appropriate use directions and precautions for aerial application on currently registered product labels. Registrants of new active ingredients are expected to provide data and/or documented field experience to support directions for aerial use.

S.W. Ormrod
Director
Pesticides Division
Plant Products & Quarantine Directorate

This replaces Memorandum T-1-213 dated February 14, 1980

Distribution: PP, KK, JZ, KL, KN, KP, KQ, KR, KV, PW, PX.

Figure 1. Current trade memorandum respecting aerial application of pesticides.

Paper No. IV-C

AERIAL SPRAYING AND THE COURTS

C.S. Brandley
Solicitor, Alberta Agriculture
Agriculture Center
Lethbridge, Alberta
T1J 4C7

LIABILITY FOR DANGEROUS ACTIVITIES ON LAND

1. When is One Liable?

   Broadly speaking, the entire field of liability may be divided according to its purposes into criminal, tortious, contractual and quasi-contractual law. Each of these is distinguishable by the nature of the conduct or its consequences and the purpose for which legal remedies are given.

2. What is a Tort?

   Tort liability exists primarily to compensate the person injured by compelling the wrong doer to pay for the damages he has done.

   The law of torts, then, is concerned with the allocation of losses incident to man's activities in modern society; in short doing all the things that constitute modern living. There must therefore, of necessity, be losses or injuries of many kinds sustained as a result of the activities of others. The purpose of the law of torts is to adjust these losses and afford compensation for injuries sustained by one person as a result of the conduct of another.

   There are three bases upon one of which every case of tortious liability has to rest. These are:

   (1) An intent to interfere with another's property (nuisance).

(2) Negligence - conduct falling below the standard established for the protection of others against unreasonable risk or harm. The standard of conduct is ordinarily measured by what the 'reasonable man' would do under the circumstances.

(3) Strict liability or liability without 'fault'

THE PRINCIPLE OF RYLANDS VS FLETCHER

The modern doctrine of strict liability for the escape of dangerous substances began in 1866, in the leading case of Rylands and Fletcher. The defendant Millowners decided to construct a water reservoir on their land for the purpose of supplying water to their factory. On the chosen site there was a disused shaft of an abandoned mine, but owing to the negligence of the engineers, a firm of independent contractors who had been entrusted with the work, this fact was not discovered until the water broke into the shaft and flooded the plaintiff's adjoining mine through communicating passages. An arbitrator found that the defendants themselves had been ignorant of the existence of the old shaft and exonerated them from Personal negligence. Nonetheless, they were held liable for the damages on the principle that a person who for his own purposes brings on his lands and collects and keeps there anything likely to do mischief if it escapes, must keep it in at his peril, and, if he does not so do, is prima facie answerable for all the damage which is the natural consequence of its escape.

NATURAL OR NON-NATURAL USE OF LAND

The rule set out above is strict liability or liability without fault. However, in the intervening years some limitations to the strict rule of Rylands vs Fletcher has emerged. The most significant change is that the use which the landowner is making of his land must be some special use bringing with it increased danger to others - not merely the ordinary use of the land or such a use as is proper for the general benefit of the community. In applying this qualification, the courts have looked not only to the thing or activity in isolation, but also to the place and manner in which it is maintained and its relation to its surrounding. Time, place and circumstances, not excluding purpose, are most material. Thus the storage of water in a reservoir for industrial purposes may create a danger in a particular locality, but the accumulation of water for irrigation is a proper method of using land in an ordinary manner, at least in a proclaimed irrigation district (Fleming).

Although the above appears very clear, what in fact constitutes a natural or a non-natural use is a question open to as many answers as there are uses of land.

CASE LAW IN CANADA - Aerial Spraying
MIHALCHUK v. RATKE - 55W.W.R. 555. 1966.
Saskatchewan Queens Bench,
Justice MacPherson.

The farmer engaged an aerial spraying company to spray his barley crop with a herbicide. A light breeze carried the spray to the neighbour's rape crop which was particularly sensitive to the herbicide (2,4-D).

If there was any negligence, it was that of the aircraft company, not the farmer. But could the farmer be found liable under the rule in Rylands vs Fletcher? The court answered clearly he could. He had brought unto his land something likely to cause damage if it escaped and it had escaped. Thus there was a liability without any negligence on the part of the farmer, subject only to the question of whether his use of the land in this way was a natural or non-natural use. The court said that while the growth and production of crops was clearly a natural use and the control of weeds was part of growing a crop, the use of aircraft for this purpose constituted an unusual operation, or non-natural use thus making the farmer liable. This method brought increased danger to others due to the speed and height of the aircraft and the oil mixture.

Justice MacPherson made the following observations:

a) The herbicide was mixed with oil.

b) Oil has a lower surface tension than water and droplets are smaller.

c) An oil drop is small, light and capable of drifting great distances.

Justice MacPherson also quoted the following authorities:

a) Salmon on Torts - p. 441.

> "The occupier of land who brings and keeps upon it anything likely to do damage if it escapes is bound at his peril to prevent its escape, and is liable for all the direct consequences of its escape even if he had been guilty of no negligence".

b) Lord Cairns, in the House of Lords judgement in Rylands v. Fletcher p. 346 laid down that only where the defendants use was non-natural was liability absolute.

c) Lord Moulton, in Richard v. Lothian (1913) AC 280. stated, "It is not every use to which land is put that brings into play that principal (Rylands v. Fletcher). It must be some special use bringing with it increased danger to others, and must not merely be the ordinary use of the land or such as is proper for the general benefit of the community".

Wells v. King, Peace Air Ltd. and Birch Hill Farms Ltd. 1974. Alberta Supreme Court, Justice Lieberman.

The farmer engaged an aerial spraying company to spray his barley crop. There was a wind blowing at the time of the application at the velocity of about 12 miles per hour.

Justice Lieberman followed in entirety the reasoning of Justice MacPherson in the Mihalchuk v. Ratke case. The aerial spraying was a non-natural use of land and there was strict liability.

Bridges Bros. Ltd. v. Forest Protection Ltd. 72 D.L.R. 335. 1976.

New Brunswick Supreme Court, Queen's Bench Division, Justice Stephens.

The defendants aerial spraying of insecticide to control spruce budworm also killed bees that pollinated the Plaintiffs blueberry fields.

Justice Stephens held that the defendant ought to have known that the chemical (fenitrothion) would be toxic to native bees. The defendant in flying over and close to the Plaintiffs fields failed to use reasonable care to prevent insecticide from falling upon or drifting unto such fields. Failure to use reasonable care amounted in law to negligence. The Defendant's argument that his action was protected under the Forests Service Act, which empowered the Minister to delegate authority to carry out the purpose of the act, could not be applied as the delegation of authority must be made formally and there was no evidence of such delegation.

Cruise v. Niessen - 82 D.L.R. 190. 1977.
Manitoba Queen's Bench,
Justice Solomon.
Manitoba Court of Appeal
Justice Grey, Mannin & Matas

The Plaintiff and the Defendants were adjoining farmers. The Defendants hired an aerial applicator, being an independent contractor, to spray with MCPA (a herbicide designed to control broad leaf weeds).

The Plaintiff had previously sprayed his flax crop with ground tractor machinery applying MCPA mixed with TCA, but claimed the drift from the aerial spraying caused the damage to his crop. However, the flax had no signs of kink in their stalks.

Justice Solomon held the Defendants liable under the rule in Rylands v. Fletcher. He further stated, "I agree with the corporate Defendant that aerial spraying with herbicides by farmers can no longer be regarded as an unusual operation. Generally speaking, farmers have accepted aerial herbicide spraying of crops as standard good farming management on cereal growing farms. This acceptance of aerial spraying procedure, however, does not relieve the person using such method from the responsibility for damages such operation would do to neighbour's crops if the herbicide so applied is permitted to escape and damage crops on a neighbour's land. It does not make any difference whether the application of the herbicide is by ground or by the aerial spraying method".

The owner was duty bound to prevent the MCPA herbicide from escaping onto the Plaintiffs land and therefore cannot escape the responsibility attaching on them of seeing that the duty is performed by delegating it to a general contractor.

The trial Judge went on to discuss the likelihood of escape of herbicide from the air and said there is far less chance of escape from a ground spraying operation.

The Court of Appeal held there was no evidence to support the allegation of drift from the aerial spraying, and the Plaintiffs poor crop was found to have been caused by his own faulty application of herbicides.

Bartel v. Ector 90 D.L.R. 89. 1978.
Saskatchewan Queen's Bench,
Justice Estey.

A landowner employed an aerial spray applicator to spray herbicide on his barley crop. The spray drifted onto the neighbour's land damaging his trees.

The landowner and pilot were jointly liable because the pilot was negligent and the rule of strict liability applied to the owner. He followed the statement of Justice Solomon in the Cruise v. Niessen.

Schunicht v. Tiede. 1979.
Alberta Queen's Bench,
Justice Crossley.

The aerial applicator was spraying the owner's land when the wind was blowing.

Justice Crossley stated, "I conclude that because of its unusual nature and the increased danger to others the defendants operations was a special use and not a natural use of their land. The principal of Rylands v. Fletcher therefore applied and the defendants are liable. The case herein comes squarely within the aspects considered by Justice MacPherson in the Ratke Case and on the basis of his comments I would certainly award damages to the Plaintiff."

Fingas v. Summerfeld Colony of Hutterian Brethern 5
Manitoba Reports, 1981, p. 361. 1981.
County Court Judge Ferg,
Manitoba Court of Appeal.
Justice Matas, O'Sullivan & Huband.

The owners of the land used a spray coupe type of sprayer to spray their barley crop with MCPA amine. There was a breeze blowing and the drift damaged the neighbour's sunflower crop. The owner used small or fine spray nozzles even though they had larger nozzles which were safer.

County Court Judge Ferg Stated that as the spray coupe (using 4 gallons of water per acre compared to a pull type sprayer using 10 gallons per acre) significantly increased the risk of spray drifting if there is any air movement at the time. The Court of Appeal likened the use of the spray coupe to aerial spraying and maintained the two methods were about equally dangerous in so far as the risk of drifting was concerned. The strict Liability of Rylands v. Fletcher applied.

Gotreaux v. Gray 1957 Lousiana - Supreme Court.
Young v. Darter 1961 - Oklahoma - Supreme Court.

The above United States cases have applied the Rule of Strict Liability for drift damage from aerial application.

CONCLUSION

It is very difficult, if not impossible, to define what the Courts will classify as natural or non-natural use of the land. However, in Canada today, with aerial spraying of herbicides, the rule that there can be strict liability without negligence is not questioned.

Aerial spraying of weed killer next to sensitive crops on neighbouring land presents too great a danger from drift to qualify as "normal", however accepted the general practise of applying herbicide (Ibid).

SUGGESTED FUTURE ACTION

It is my humble opinion that the future role of Aviation in Agriculture as it relates to insecticide and herbicide application will depend on:

1) The quality of work.
2) The price of the service.

Strict liability, whether negligent or not, for spray drift imposes an unreasonably high duty of care on the aerial applictor and the owner of the land. This in turn results in higher costs for the service because of the frequent damage actions.

Statutory Authority could provide an exception to the rule of strict liability. Legislation could be enacted in each Province providing immunity for any harmful consequences which occur, without negligence, in the normal operation of aerial spraying. With such legislation the "reasonable man" doctrine would be able to set the required standard of care. Aerial spraying of herbicides by farmers would no longer be regarded as an unusual operation. In the meantime the law in Canada is clear. There is strict liability, without negligence, for damages resulting from aerial spraying. Statutory Authority completely eliminating "strict liability" could relegate each claim to proof of negligence.

REFRENCES

John G. Fleming, *The Law of Torts*, The Carswell Company Agincourt, Ontario, 6th ed., p. 309.

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Paper No. V-A

AERIAL APPLICATION METHODS

W.E. Yates
Agricultural Engineering Department
University of California
Davis, California 95616

ABSTRACT

The agricultural aircraft industry is relatively young and has produced a rapid advancement in technology over the past 25 years. This paper reviews the developments in new equipment, materials and application techniques that can provide economic and efficient control of certain agricultural pests and at the same time maintain a safe environment for people, plants and animals in non-target areas.

Aircraft. New fixed wing and rotary wing aircraft are available with a wide range in speed and payload capacity.

Spray Systems. Numerous types of light weight centrifugal pumps, diaphram check valves, suck back valves, screens and stream- lined booms are available. Control of the drop size spectrum is probably the most important factor related to both biological efficacy and potential drift hazards. Data from new laser drop measurement systems shows the potential drift hazard and coverage produced by different atomization systems. A new laminar microjet nozzle offers a potential improvement for ultra low volume (ULV) applications.

New Developments and Theoretical Models. New developments include introduction of electronic guidance systems and use of vegetable oil carriers for ULV applications. NASA has developed theoretical models that predict trajectories of spray particles released from an aircraft.

Future Trends and Research Needs. A key to improved efficacy, reduced drift hazards and lower application costs is a practical system for producing a uniform drop size for ULV applications. Research is also needed on biological efficacy related to drop size and application parameters.

INTRODUCTION

The agricultural aircraft industry serves as an important component in the efficient production of food and fiber in many countries. The worldwide use of agricultural aircraft was estimated at treating 235 million hectares during 1976. In the U.S., during the same period, agricultural aircraft covered approximately 72 million hectares, which represents about 27% of all pesticide treatments. In the state of California, agricultural aircraft are utilized for approximately 50% of the area treated with pesticides. Agricultural aircraft are used because they offer a unique cost effective method of applying many organic pesticides. Some of the unique features of aerial applications are: rapid treatment of large areas; lower cost for certain applications; no damage to the crop due to vehicle tracks; treatment can be made over flooded rice fields, over poorly drained areas, over mountainous terrain, over brush or forest covered areas, or after rain or irrigation. Although a great deal of progress has been accomplished in aerial application methods, there is an urgent need to reduce some of the current hazards, improve the precision and efficacy of applications and reduce application costs. In my discussion I plan to illustrate some of the important technological developments in aerial application methods; point out some of the urgent unsolved technical problems; and identify some priorities for research and development

TYPES OF AIRCRAFT

Fixed Wing

The history of the use of aircraft in agriculture dates back to the early 1900's. In the United States the first well documented case was in Ohio in August 1921, when a grove of catalpa trees were dusted with lead arsenate for control of Catalpa Sphinx Caterpillars. A Curtis JN6 (Hisso-Jenny) was equipped with a crude hopper for dispensing the dust from the fuselage for this successful application. Although the use of aircraft continued to expand during the 30's and 40's it was not until after World War II that the industry began its rapid expansion. By 1950, in the USA the C.A.A. listed some 5000 aircraft in agricultural work. These "first generation" aircraft were all aircraft designed for the Military or general aviation. The most popular aircraft were the Boeing-Stearman or the Navy N3N biplanes, both rugged military, trainer aircraft. Most of the aircraft were fitted with hoppers in place of the front cockpit and the original 220 h.p. engine replaced with an available surplus 450 h.p. radial engine. The operator usually designed and built his own conversion for agricultural applications.

The "second generation" aircraft followed in the early fifties. During 1949-50, Fred Weike designed and built the first aircraft for the purpose of distributing agricultural materials, the AG-1. This design gave careful attention to high payload/horsepower, flight characteristics, protection of the pilot in a crash, hopper location, maintenance and repair. Many of the AG-1 design concepts were incorporated into the Piper "Pawnee". Since that time a variety of agricultural aircraft designs with a wide range of operating capabilities have been introduced. Table 1 is not a complete compilation but illustrates the general range in power, capacity and speed of the new designs. The aircraft with the horizontal opposed engines are new engines and have the lowest range of power, 235 to 400 h.p., and the smallest hopper capacities, 568 to 1041 liters. All of the designs with radial engines, except the PZL (Poland), are based on a supply of military surplus engines. The most common are the Pratt & Whitney 450 and 600 h.p. models. The largest radial engine is the Wright 1200 h.p. engine used on the Bull Trush. The various aircraft designs utilizing the radial engines have a hopper capacity from 757 to 2498 liters. The aircraft with the largest hopper is the Polish built Dromander which utilizes a large new radial engine with a rated horsepower of 967. The "third generation" aircraft were designed around the turbine engine with a range in power from 500 to 750 h.p. The hopper capacity ranges from 1287 to 2271 liters. The cleaner aerodynamic design with turbine engines also results in higher airspeeds with application speed ranging from 193 to 225 km/h. The newest breed of aircraft that has been introduced as a potential for agricultural spraying is the "ultralight" aircraft. The Goldwing, Table 1, illustrates the very low power, 30 h.p., and low capacity, 57 liters of such aircraft. Thus, the ultralights will be generally limited to ultra-low-volume applications. In the U.S., no commercial spraying is currently allowed with any ultralight. This is because none of the ultralights have received an air worthiness type certificate.

Although a variety of aircraft are available, it is apparent that further basic research is required to develop an integrated aircraft distribution system. All present designs are based on the needs of the pilot and operator, i.e., as a truck for efficient transportation from point A to B, not as an efficient distributor of sprayed or solid materials. This will be discussed at greater length under the section discussing spray distribution.

Rotary Wing

Helicopters are extremely versatile machines and offer the following unique characteristics that are useful for aerial applications they can: take off and land on a spot near treatment area, make shorter turns, maneuvre around complex terrain, and adjust forward speed to control wake action. The major disadvantages are the high initial cost and high maintenance costs. In addition, payload capacity is also significantly less (about half) than for the same power in a fixed wing aircraft. Table 2 illustrates the capacities of two general classes of helicopters used in agriculture. The "first" generation are the piston engine helicopters with power in a range from 190 to 305 h.p. and with a hopper capacity from 341 to 416 liters. The "second" generation helicopters utilize turbine engines which produced an important increase in payloads. The rated horsepower ranges from 317 to 1250 h.p. with a hopper capacity from 606 to 1514 liters. In the U.S., helicopters represent about 10% of the total number of agricultural aircraft. The use will probably remain limited to applications where the unique characteristics are required and the method is cost effective, i.e., forestry application in mountainous areas, orchards, small fields, etc. Further research is needed to establish the effect of vortex strength on spray distribution and coverage in different crop canopies.

SPRAY SYSTEMS

Spray Pumps and Drive Systems

A number of independent manufacturers offer custom spray components for most of the new agricultural aircraft. Cast aluminum centrifugal pumps are the most popular. The rotational speed can be readily regulated to provide a wide range in pressure and flow rate. An enclosed variable speed hydraulic motor is the most efficient drive system but also the most expensive. The simple, direct coupled windmill drive is the lowest cost and probably the most popular. An in-flight adjustable pitch windmill drive is also available.

Booms, Valves, and Strainers

Spray booms are available in aluminum or stainless steel, and in either round or streamlined shape. Diaphram check valves and venturi suck back valves are important components that provide a rapid shut off of spray at the end of a swath.

Nozzle

The atomization system that is commonly employed is a boom and nozzle arrangement with hollow cone, solid cone, or flat fan nozzles. The nozzles are the same types designed for industrial or ground agricultural equipment that operate under nearly static conditions. Also, a variety of rotary cage atomizer units driven by windmill blades, electric motors, or hydraulic motors, have been introduced and are used primarily for low volume applications. During the early stages in the use of agricultural aircraft, the information on nozzle selection for different applications was developed primarily by "trial and error" testing by aerial applicators and farmers. More recently there has been a modest amount of research on aerial application techniques by chemical manufacturers, universities and government agencies. Very little research on nozzle selection has been conducted by air frame or nozzle manufacturers.

The drop size spectrum is one of the most important application factors related to the biological efficacy and potential drift hazards. The atomization process on agricultural aircraft is very complex and there is very little precise quantitative data available on the drop size spectra from different nozzles and operating parameters. Early research on droplet spectrums were fraught with many sampling and measurement problems.

Most procedures were based on collection of drops on paper, hydrophobic coated glass slides, magnesium oxide coated slides, oil immersion or air samplers. The above procedures may give erroneous data for aerial applications because all drops from agricultural aircraft may not deposit on sample plates and/or errors in spread factors may result in large errors in volume determinations because diameter values are cubed. However, in recent years several new laser instruments linked with digital computers have revolutionized measurement of drop spectra. There are only a few being used in agricultural aircraft research: Dr. Bouse, USDA, ARS at Texas A&M; Dr. Picot, University of New Brunswick; and our group at University of California, Davis. At Davis, we have a particle measurement system (P.M.S., Boulder, Colorado) with two probes and a dedicated computer. One probe produces a 2 dimensional shadow image of each particle that passes through the laser beam. The particles are classified into 62 size classes from 23 to 2062 micrometers. Our second probe is based on forward light scattering and is capable of measuring particles from 1 to 95 micrometers. It is of course important that adequate test procedures and evaluations are established to obtain the overall average temporal drop size distribution across the entire spray pattern. We have made drop size spectra measurements in flight on a DeHavilland "Beaver" aircraft and with simulated conditions in a wind tunnel.

Published results of drop size data from the modern laser instruments is very limited. There is indeed, need for considerable more research to establish the atomization characteristics over a wide array of parameters. Some of the important parameters are: nozzle design, flow rate, pressure, air speed, orientation angle, surface tension and viscosity.

Bouse and Carlton (1)* reported on a series of tests with small fan nozzles and simulated pyrethroid formulations in a base of vegetable oil. We have reported limited studies of drop spectra from various nozzle designs with water spray (2,3,4) and a few studies with a small fan nozzle and formulations of Bacillus thuringiensis (5).

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*See list of references

We have conducted a limited array of tests with commercially available nozzles. In general, all hollow cone, flat fan and rotary cage nozzles produce a relatively broad spectra of drop sizes. Figure 1 illustrates a typical drop size spectrum with a volume median diameter of 340 µm. For this hollow cone nozzle (D6-45) 10% of the spray volume is in spray drops less than 217 µm and 10% of the volume in drops larger than 500 µm. Although the flow rate and other parameters may affect the median diameter, the relative uniformity of the spectrum is nearly the same for different nozzle types with the same median diameter. This can be explained by the fact that the atomization process for a cone, fan or rotary nozzle produces an unstable liquid film that forms ligaments which are shattered in an airstream.

One noteworthy development of a different concept is the microfoil nozzle introduced by Am Chem Chemical Company several years ago. This unit reduces the number of fine particles by utilizing micro-jet tubes along the trailing edge of an airfoil. This is very effective at air speeds less than 100 km/h, but not effective at higher speeds because of droplet shatter resulting from the high aerodynamic forces.

We have investigated several concepts for producing monodisperse sprays from fixed wing aircraft at speeds of approximately 160 km/h. The most successful results have been achieved by utilizing a combination of a multiple pulsed microjet system with a laminar flow aerodynamic shield. Figure 2 illustrates a cross section of the nozzle body with a modified NACA 0012 airfoil section and internal micro-orifices. The liquid system utilizes a piezoelectric transducer to provide high frequency pulses matched to the theoretical Raleigh wavelength of 4.508 dj. Figure 3 illustrates the very narrow drop size spectrum produced by the above nozzle (Figure 2) at 166 km/h and a pulse frequency of 12 kHz. The volume median diameter was 297 μm, with only 0.8% of the volume less than 219 μm and less than 2% of the spray in drops larger than 500 μm. The above system has obvious limitations and operational problems due to the very small orifices of 125 μm diameter. However, it is possible that completely closed systems could be designed and used with soluble ULV formulations. It is obvious that a great deal more research should be directed toward systems that can produce narrow drop size spectra.

SPRAY EFFICACY STUDIES

The principal objective of aerial applications is to apply a material in a manner that will effectively control a given pest or improve the environment of plants or animals. The absolute spray efficiency is very difficult to define since the required spray deposit and coverage is not well defined for each pesticide or chemical. However, the following are some of the important areas of research that need to be considered to assess and improve agricultural aviation methods: swath patterns, aircraft guidance, deposition in crop canopies and biological control. I will only try ot point out the status and importance of these above areas.

Swath Patterns

The overall uniformity of spray distribution is affected by the swath pattern or lateral spray distribution of a single swath and the swath spacing. The spray pattern is affected by the drop size spectrum, aircraft type, aircraft load, aircraft airspeed, height of flight and micrometeorological factors. Thus, it is quite difficult to predict the optimum swath spacing. Early investigations of swath patterns were conducted by progressive aerial applicators. The techniques were visual and involved spraying a dye solution onto adding machine paper placed on the ground or a chemical was sprayed onto sensitive paper. Later research introduced quantitative techniques for measuring tracer deposits with a colorimeter (6) or a flame spectrophotometer (7,8,9). The early studies of depositions from single nozzles at various locations revealed the complex effect of the air wake on the spray pattern. A few effective asymmetrical nozzle arrangements were identified. After a reasonably smooth single pattern was established, the theoretical overlapped pattern was calculated for a series of swath spacings. The coefficient of variation of deposits within the overlapped interval can be used to select the optimum swath spacing. Figure 4 illustrates the coefficient of variation of selected patterns from three different aircraft. Two systems for rapid analysis of swath patterns have been developed in recent years; one at Oklahoma State University by Roth, Whitney and Kuhlman and another by Carleton and Bouse, USDA, ARS at Texas A&M. These units have attracted considerable interest of operators and have been good educational tools at "fly-ins". However, a substantial amount of research is still needed to evaluate the large array of variables affecting distribution patterns. The availability of the above equipment will greatly accelerate research work in this area.

One additional tool that was recently completed is the NASA "Ag Disp" theoretical computer model (10). This computer model calculates the mean particle trajectory as well as the variance from the mean resulting from fluid fluctuations. The model includes the effect of wing circulation, propellor slip stream, wind velocity profile, and evaporation. To date the model has not been fully verified by experimental data. However, the model will no doubt serve as an important step towards understanding the complex factors affecting the deposition pattern and provide guidance to improve the uniformity of swath patterns. One application that NASA introduced was a study on the effect of winglets on the spray distribution pattern. A Thrush aircraft was fitted with the winglets and a few tests were conducted with solid particles to verify the computer calculations. This type of approach needs to be expanded and other design features evaluated in an effort to improve spray distribution patterns. One important economic consideration is the evaluation of design factors that may increase the effective swath width.

Aircraft Guidance

One of the requirements for uniform distribution of materials is that the pilot must execute a series of predetermined, evenly spaced parallel flight lines over the target area. In flat agricultural areas most operators rely upon two flagmen to progressively provide alignment for each flight line. In complex terrain covered with brush, forests or swamps, manual flagging may be impractical and the flight line is frequently left to pilot judgment. Another system that has received considerable usage in certain areas is the release of paper streamers or smoke bombs at the beginning and end of each pass. Other systems with permanent alternate colored flags or a series of lights have been used. The British "Decca" system was the first electronic system used to guide single and multiengine aircraft for application of pesticides to large blocks with a wide swath spacing. More recently the Litton inertial navigation system was programmed and used on multiengine aircraft for insecticide applications on forests in Quebec. The above systems are not suitable for applications of small low flying aircraft requiring narrow swath spacings. Recently, Motorola and Del Norte introduced small electronic positioning systems with an accuracy and precision compatible with small low flying aircraft. Both systems require the placement of two line of sight transponders on the ground and an aircraft radar transmitter, receiver and digital computer. The systems have not gained wide acceptance; probably because of high cost, the requirement for line of sight to both transponders at all times, and potential interference causing occasional spurious readings.

Thus, there is still a need for further development of low cost guidance systems that can improve accuracy and efficiency of aerial applications.

Deposition in Crop Canopies

A very limited amount of research has been conducted to evaluate the effect of various aerial application parameters on spray deposition within different plant canopies. Bouse (11) evaluated penetration through dense canopies of brush and trees, Kilgore et al. (12) studied spray distribution within almond orchards, and Yates et al. (13) reported spray distribution in dormant peach orchards. Carlton et al. (14) evaluated spray distribution in soybeans. A great deal more research is needed to evaluate spray deposition characteristics in plant canopies. Monodisperse drop size atomizers would facilitate research studies designed to evaluate drop deposition characteristics.

Biological Control

The overall objective of most aerial applications is the control of weeds, insects or plant diseases. Numerous field tests are conducted each year to determine the overall efficacy of aerial applications to specific chemical, crop, pest combinations. This work is conducted by chemical companies, universities, and government agencies. This type of work needs to be continued. It is recommended that the efficacy trials be expanded to collect quantitative data of spray deposition on target sites, i.e., type of coverage and mass of pesticide per unit area which can be used to develop dose response curves for each type of application.

DRIFT PROBLEMS

Spray drift is one of the most important problems facing the agricultural aircraft industry. Spray drift may be defined as the movement of fine spray particles out of the target area. Drift of even minute amounts of certain pesticides may present a hazard to people, livestock, crops, or disrupt the agro-ecosystem. The drift of 2-4D and related compounds has been recognized as a potential hazard for a long time. Drift of these herbicides have caused damage or symptoms on sensitive plants several kilometers downwind. Inhalation of spray particles or vapors as well as impingement on skin and clothing may pose a hazard to farm workers or others nearby. Drift onto edible crops near harvest time or into water supplies may pose a health hazard. Also, low levels of drift may have a serious long term effect on wildlife and the agro-ecosystem.

Prediction of the magnitude of spray drift fallout at various distances downwind is very complex and affected by many factors. The following are some of the important parameters affecting spray drift: atomization systems, spray formulations, meteorological conditions, aircraft selection and operation.

Atomization Systems

The basic source of spray drift is the small droplets that have a very low terminal velocity. Unfortunately, all conventional nozzles produce some small particles that may drift. In general, the larger the volume mean diameter, the smaller the percent volume that may drift. Figure 5 illustrates the correlation of the percent volume less than 154 µm (high drift potential) and the volume median drop diameter for a wide variety of nozzle test conditions with fan and hollow cone nozzles (4). Numerous field trials were also conducted to measure the fallout downwind from aerial applications with various nozzle types (15). Figure 6 illustrates the log-log regression curves representing the fallout deposits at various distances downwind for various applications. Use of microjets (Microfoil) on a helicopter at 71 km/h produced the lowest drift of all aerial applications.

Spray Formulations

The physical properties of the spray formulation may have a direct effect on the atomization and evaporation properties of the spray. A variety of adjuvants are available that can be used to modify the surface tension, viscosity, and viscoelasticity of the spray. Several viscoelastic polymer adjuvants have been introduced to increase deposition and reduce drift. Figure 6 shows that ground application with Nalco-Trol (N.T.) produced about half the drift as a similar ground application with 8003 nozzles. However, aircraft applications (D6 back and D6 back N.T.) revealed no significant difference in drift deposits with or without the polymer from 50 to 400 m downwind. There is currently a great deal of interest in the use of cottonseed or soybean oil as carriers for ULV applications. Previous drift tests comparing ULV and conventional applications with rotary cage atomizers (16) revealed about twice as much fallout downwind from the ULV application as from the dilute application.

Meteorological Conditions

Wind direction and atmospheric turbulence are two basic factors affecting the transport and diffusion of the fine spray droplets. A smoke plume is an excellent indicator of wind direction, velocity, and turbulence. Some operators utilize a smoke generator on their aircraft to check conditions along the field boundary prior to the application. Atmospheric turbulence can be characterized by a number of different indices such as Richardson's Number, standard deviation of velocity variations, and stability ratio. We found that the stability ratio does correlate with drift deposits and is relatively easy to measure. The stability ratio (S.R.) is defined as follows:

$$\text{S.R.} = \frac{T_{10} - T_{2.5}}{U_5^2} 10^5$$

where: T is temperature in °C and U is average wind velocity in cm/s. The subscripts refer to the measurement height in meters.

A typical range of stability conditions are:

Stability Ratio	Conditions
1.2 to 7.0	very stable
0.1 to 1.2	stable
-0.1 to 0.1	neutral
-0.1 to -1.7	unstable

A number of research instruments are available to measure atmospheric turbulence. However, most units are expensive and require considerable installation time. Thus, it would be desirable to develop a low cost portable unit that could be used by aerial applicators to provide a permanent record of the turbulence, wind direction and wind velocity at each application site.

Numerous field trials were conducted to determine the effect of micrometerological conditions on the drift fallout characteristics (17). Figure 7 shows that the fallout deposits generally increase as the stability ratio increases. For example the fallout at 400 m downwind was 13 times as much during very stable conditions as compared to low stability conditions.

The U.S. Forest service has been instrumental in developing a sophisticated mathematical model of the transport and deposition of sprays applied by aircraft to large forest areas (18). Additional theoretical and field research is required to develop accurate models to predict spray drift from a multitude of application variables. The goal would be the development of a computer program that could be used on small microcomputers by laymen in the field to predict drift levels from real-time information. In this manner, decisions to stop spraying when hazardous conditions occur could be made during a specific application.

FUTURE TRENDS AND RESEARCH NEEDS

Further research is needed in the basic areas of airframe and distributor system design, atomization, spray distribution and biological efficacy, and control of drift hazards.

New airframe design concepts should be investigated based on an integrated approach to design the aircraft around the need to disperse sprays and solids in a uniform wide swath pattern.

Research needs to be expanded on determining the drop size characteristics for a large array of conventional nozzles, operating conditions and spray formulations. It appears that many new chemicals will be available that are effective at very low application rates. A key to improved efficacy, reduced drift hazard and lower application costs is a practical system for producing a uniform drop size for ULV applications. When monodisperse systems are available, extensive biological testing will be required to determine optimum droplet size for different chemical, pest, and crop combinations.

Further research is required on the use of models and field evaluations to improve spray distribution and biological efficacy of aerial applications.

Further research is needed to develop equipment and techniques for reducing spray drift hazards. Additional basic studies are required to evaluate the transport, evaporation, and diffusion of sprays released from aircraft. Hopefully theoretical models can be developed and verified that can predict the deposition in plant canopies and the downwind drift hazards from aerial applications.

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Table 1. Selected new and old fixed wing aircraft used in agriculture

Type of Engine	METO Power, h.p.	Manufacturer Model	Hopper Capacity Liters (U.S. gal.)	Application Airspeed km/h (MPH)
In-line Piston	30	Goldwing	57 (15)	97 (60)
Horizontally Opposed Piston	235	Piper--Pawnee	568 (150)	169 (105)
	285	Cessna—Ag. Truck	1060 (280)	183 (114)
	300	Eagle--DW-1	946 (250)	177 (110)
	400	Piper—Brave	1041 (275)	209 (130)
Radial-Piston	450	Boeing--Stearman	757 (200)	145 (90)
	450	Grumman--Ag. Cat	1135 (300)	161 (100)
	450	Weatherly--620	1268 (335)	177 (110)
	600	Schweizer--Ag. Cat B	1514 (400)	185 (115)
	600	Ayers--Thrush	1514 (400)	177 (110)
	600	Air Tractor—AT-301A	1325 (350)	209 (130)
	967	PZL (Poland)--M18	2499 (660)	193 (120)
	1200	Ayers—Bull Thrush	1930 (510)	225 (140)
Turbine	500	Weatherly--620 TP	1287 (340)	193 (120)
	680	Air Tractor—AT-400	1514 (400)	225 (140)
	750	Ayers-Turbo Thrush	1893 (500)	225 (140)
	750	Schweizer-Ag. Cat G164D	2271 (600)	201 (125)

Table 2. Selected new and old rotary wing aircraft used in agriculture

Type of Engine	METO Power, h.p.	Manufacturer Model	Hopper Capacity Liters (U.S. gal.)	Application Airspeed km/h (MPH)
Horizontally Opposed Piston	190	Hughes--300C	341 (90)	161 (100)
	260	Bell--47G-5	454 (120)	135 (84)
	305	Hiller--12E	416 (110)	145 (90)
Turbine	317	Bell--206A	606 (160)	211 (131)
	375	Hughes--500D	681 (180)	259 (161)
	1250	Bell--205	1514 (400)	206 (128)

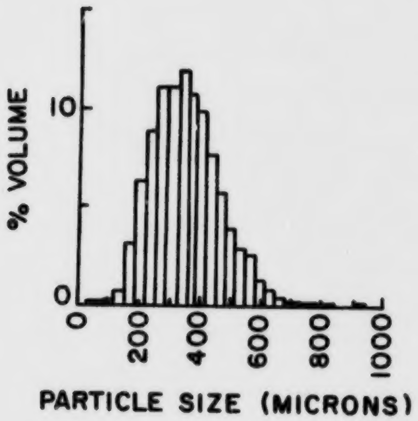

Figure 1. Histogram of Drop Size Spectra for a Hollow Cone, D6-45, Nozzle, 276 kPa, 166 km/h, Water.

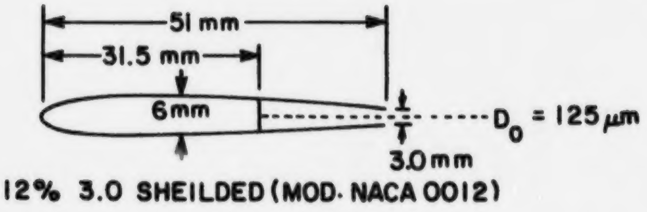
51 mm
31.5 mm
6mm
D0 = 125 μm
3.0 mm
12% 3.0 SHEILDED (MOD· NACA 0012)

Figure 2. Cross section of the aerodynamic shielded laminar microjet atomizer.

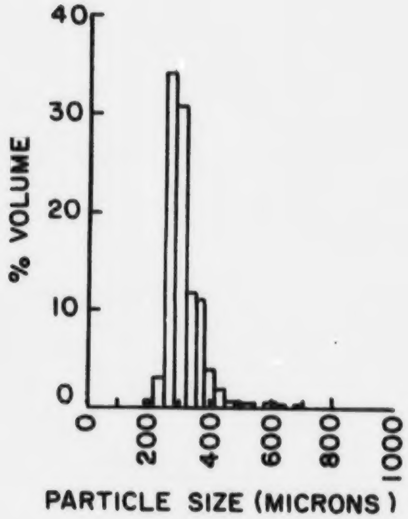

Figure 3. Histogram of Drop Size Spectra for Laminar Microjet Atomizer, 41 kPa, 166 km/h, Water.

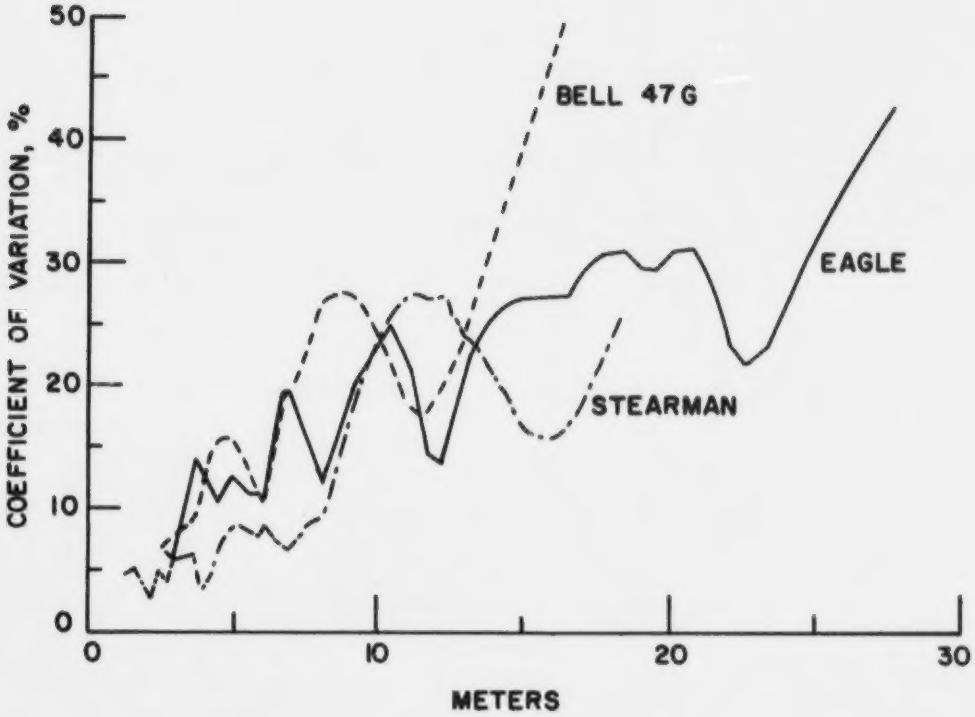

Figure 4. Theoretical effect of swath spacing on coefficient of variation of spray deposits from three different types of aircraft and spray systems.

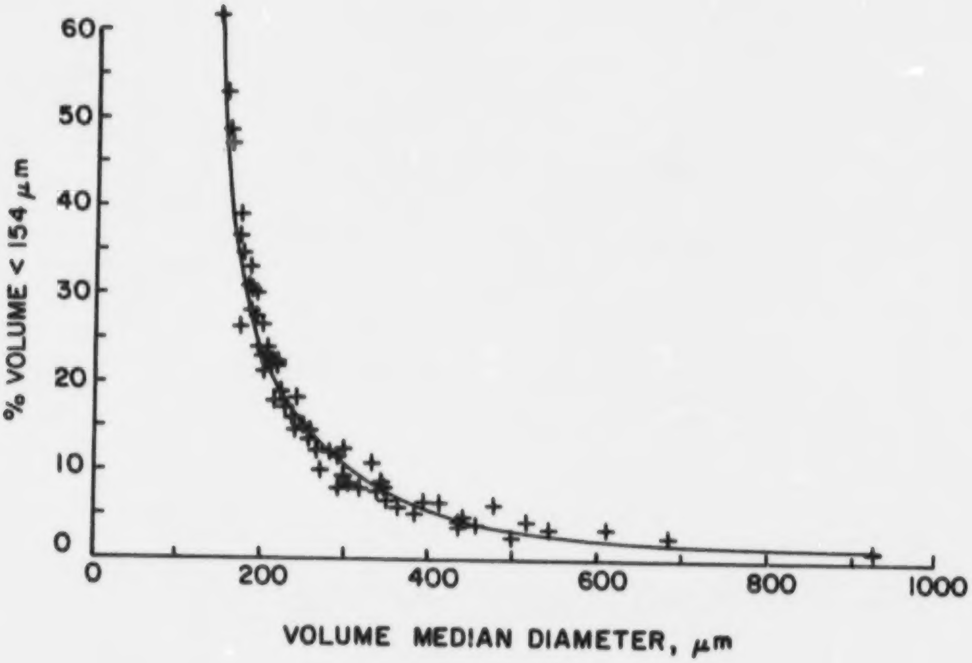

Figure 5. Effect of Volume Median Diameter on Percent of Spray Volume Less Than 154 μ.

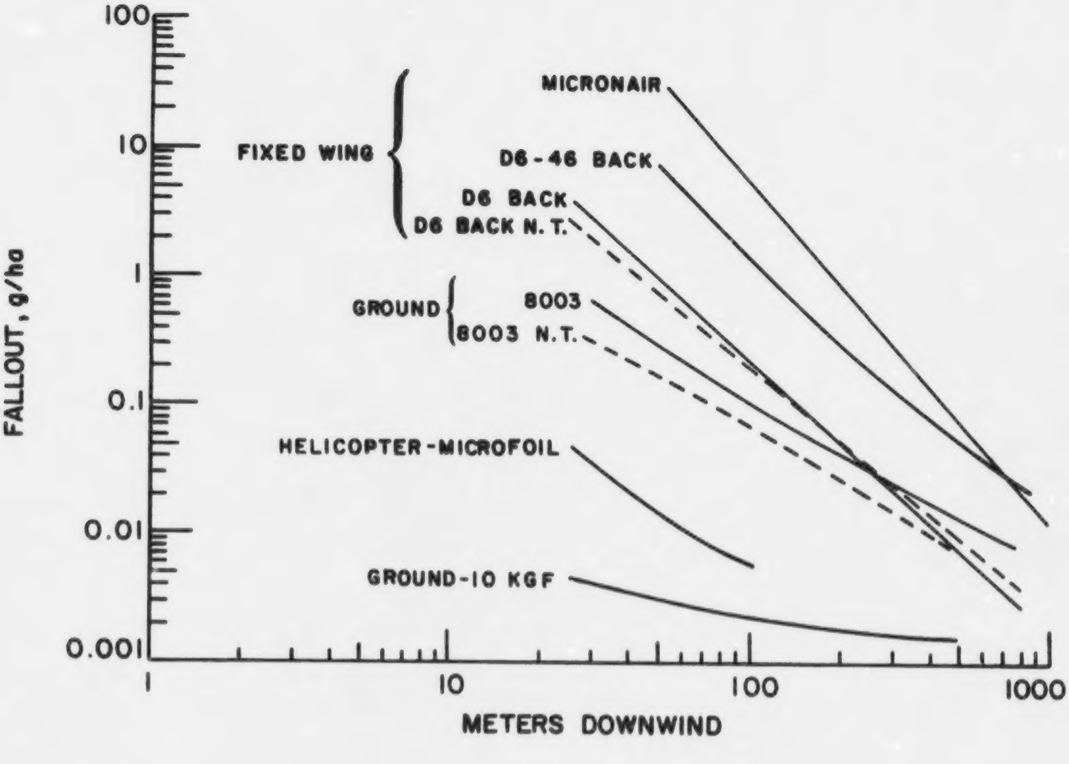

Figure 6. Effect of Types of Application Equipment on Spray Drift Deposits Downwind from Application. All Applications Normalized to 1 kg/ha Target Treatment.

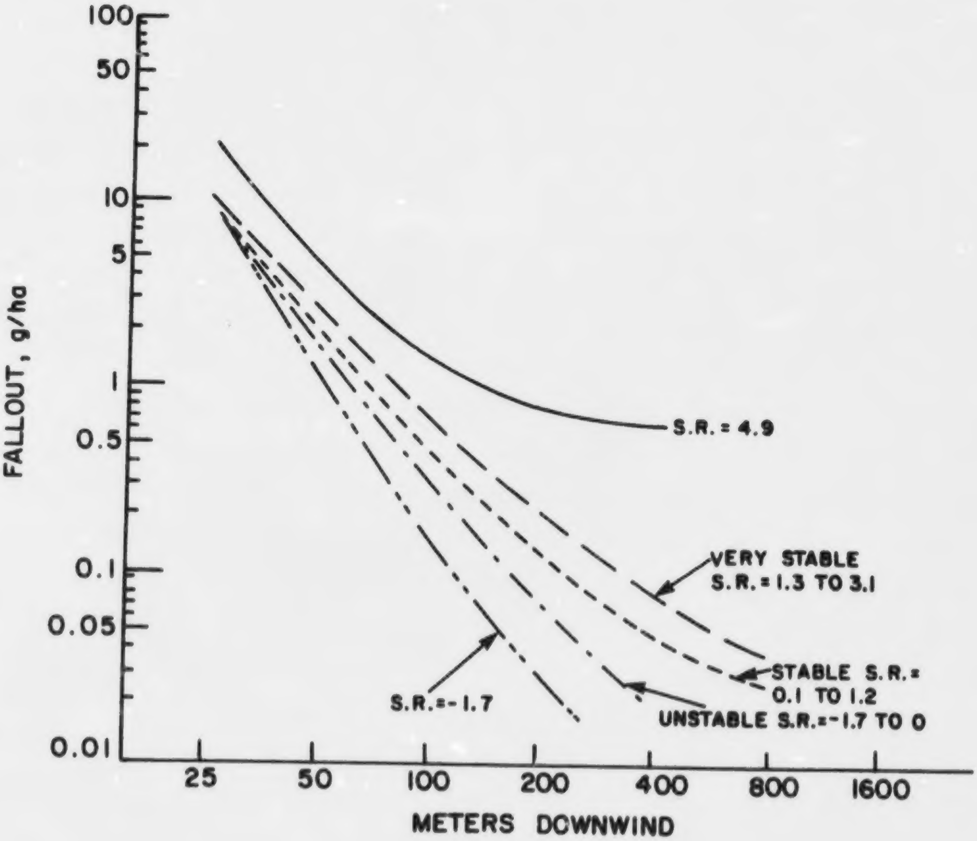

Figure 7. Effect of stability ratio on spray drift deposits downwind.

Paper No. V-B

MONITORING AND ASSESSMENT OF AERIAL SPRAY APPLICATIONS

J. Maybank
Director
Environment Section
Saskatchewan Research Council
30 Campus Drive
Saskatoon, Saskatchewan
S7N 0X1

ABSTRACT

When spray droplets of a pesticide are released above a farm field, either from an aircraft or a groundrig, it is usual to assume that they settle out by gravitation and so are deposited in that field. In perfectly still air, and in the absence of any turbulent motion from the spray vehicle, that would indeed be the case. However, as that ideal situation simply doesn't exist, it becomes essential to determine what fraction of the droplet spray does deposit on target and what fraction drifts off with the wind to become deposited eventually in some off-target area downwind of the spray operation. At the same time it is vital for considerations of chemical use efficiency and efficacy, whether for weed or insect control, to ascertain how uniform the target deposit pattern is, and to seek ways to improve this important parameter.

Once a droplet is released, two key properties begin to act one upon the other. The first is the air motion, itself a complex mix of windspeed, aircraft speed, and turbulence produced both by the aircraft and naturally present in the air over any sun-warmed field. The second key property is the droplet size distribution, as each size is affected differently by the air motion, and so acquires a different trajectory. Should water be a major component

of the spray solution, air temperature and relative humidity come into consideration, for droplet evaporation may rapidly alter the size distribution and convert more of the spray into smaller drift prone droplets. Finally, of course, it should be recognized that for reasons of efficacy, useful deposit patterns of insecticides and herbicides within the target area may well differ in droplet spectra; this has implications in turn for the magnitude of off-target drift and for the hazards that may be produced downwind.

Laboratory tests on nozzles, sprayer pressures, and chemical solutions are valuable in establishing what combinations might be most successful. Biological tests for efficacy, carried out conjointly, can help identify optimum droplet size ranges for specific pests and chemicals. Such experiments have successfully screened out modifications that have potential merit from a much more numerous collection of unpromising approaches. The best ones can then be tested in the field, under full operation of turbulent air motions and aircraft effects on the spray cloud. In such field trials, samples of the deposit pattern must be collected and/or foliage and soil examined for the droplets deposited on them. These can then be related to the biological properties of the active ingredient to determine if satisfactory pest control had been achieved. For off-target drift, air samples as well as droplet deposits are commonly collected and the amounts related to the susceptibilities of downwind crops, shelter belts, insects, fish, etc. to estimate the hazards incurred.

The real proof of spray droplet deposit and off-target drift behaviour may be found from monitoring full scale field operations and comparing the results with various theories and models. As might be expected, deposit patterns from aircraft are inherently less uniform in the target area than are those put down by groundrig sprayers. Obviously, there can be a trade-off here between the aircraft's advantages (e.g. speed, ability to spray a full-grown crop) and the reduction in deposit uniformity. It is less easy to justify such a trade-off in off-target drift amounts; these are clearly going to be greater for aircraft than for a groundrig. However, there will be some downwind distance beyond which the two methods produce essentially the same drift fraction. Finding that distance and how it might vary with winds is a major research task for the future.

INTRODUCTION - SPRAY PRODUCTION

In this review three related questions will be addressed: (i) how spray is deposited on the target; (ii) how efficacy can be assessed and (iii) how off-target drift can be monitored and controlled. While the primary interest here naturally involves aerial application, it will be instructive to examine groundrig application as well. In the first place, considerably more research has been carried out, in Canada at least, on agricultural pesticides applied by groundrig than by aircraft. In the second place, as I shall attempt to show, the drifting droplet, as it moves downwind, eventually loses all memory of its origin. In short, drift is drift, regardless of the vehicle from which the spay originated.

The starting point for spray is clearly the nozzle tip from which the solution emerges as an unstable sheet or filament of fluid. This quickly breaks up into droplets that may range in size from 10 μ at the small end to as large 1000 μ (1 mm) or more, at the other extreme.

Each droplet size possesses a distinct settling velocity, which is one of the key factors that determine its trajectory from the release point to its impact on the ground or onto foliage. Hence the droplet size spectrum that a nozzle produces is of vital concern. It is controlled by the size of the nozzle tip orifice, by the hydraulic pressure in the spray boom system and by the surface tension and viscosity of the spray solution being used. A further controlling factor is the aircraft speed and the angle at which the spray emerges into the airstream. This means that droplet size spectra for aerial operations should always be measured under airflow conditions typical of aircraft speeds.

At the moment of release each droplet is subject to a combination of three velocity components: (i) nozzle ejection speed, at some angle to the aircraft motion; (ii) a horizontal speed along the swath, imparted by the aircraft; and (iii) a horizontal speed, usually at right angles to the swath, provided by the ambient wind. The first two are quickly removed from consideration as the droplets are decelerated by friction effects, but a vertical descent term is added to the situation as the droplets begin to settle out. If these various motions were constant it would be a relatively simple matter to calculate each droplet's trajectory from release to impaction, and there would virtually 100% deposition within the target area. However, turbulence caused by both the aircraft and the local wind regime come into play and involve vertical air motions. In addition, the size of each droplet rapidly diminishes as the water component evaporates; this in turn reduces their settling velocities. When a further factor is added, namely a highly variable release height for the droplets, caused by wing tip vortex effects, the result is a wide variety of settling times and distances downwind for the droplet spray. Nevertheless, the vast majority do come down within the target area, to produce the desired deposit.

THE DEPOSIT PATTERN

The depositing droplets come to rest on the ground, or more commonly for insecticide application, on the crop foliage. The question of concern is, naturally, the uniformity of the resulting pattern. In nearly all cases with aircraft spraying, the output from individual nozzles becomes well mixed with that from adjacent ones, a feature that can be easily checked through use of strips of specially-treated paper extended across the swath width. This is frequently not the case with groundrig operation where misaligned or damaged nozzle tips may produce coverage gaps between adjacent sprays.

On the other hand, the wing tip vortex, and turbulence due to propeller-motion or "prop wash", can detrimentally affect the swath deposit. A great deal has been learned, mainly through trial and error, of the effective nozzle spacings that may improve the swath deposit, and in particular of ways to avoid the worst aspects of wing tip vortices. Each such modification appears to require the testing of specific aircraft and spray boom configurations but help has been forthcoming from wind tunnel studies and vortex-modelling calculations (Morris, 1978). As a result, streak patterns along a swath or between adjacent swaths are avoidable through on-the-spot field adjustments.

Less easily avoided, however, are random deposit variations produced primarily by air turbulence. These show up whenever a series of sample dishes are laid out along a swath. Each one naturally collects a different amount, and an average deposit density can be calculated. Where the problem shows itself, however, is in the frequently large variation of the collected amounts about this average. A typical example from one of our field trials is shown in Figure 1. The desired average is just over 50 mg/m^2, equivalent to 8 oz/acre, and for much of the area this is indeed found. However, as can be seen, some dishes collected less than half this amount, and so any weeds adjacent to them would have received only a 4 oz/acre application or less. The question naturally arises: would the weeds be adequately controlled by an average application of this amount? If so, and except for streak misses as described earlier, field operation evidence is that such an application is effective overall, then one must conclude that too much chemical is being applied, by perhaps up to a factor of two. That is, if one could ensure a more uniform deposit along the entire swath, and over an entire field, then satisfactory weed control could be achieved with a lower application rate.

THE ASSESSMENT OF EFFICACY

This brings up the entire question of herbicide and insecticide efficacy. Laboratory studies, as well as test plot data, have yielded some answers. But such approaches usually fail to address the turbulence-induced swath variability, or the equally significant factor of droplet size influence. It has seldom been possible to identify exactly what droplet size might be most effective, i.e. whether a given volume of pesticide is more effective in weed or insect control when applied in one droplet size as opposed to larger or smaller sizes.

What evidence there is suggests that the smallest herbicide volume needed to control most weeds is involved when the liquid is applied in droplets of 200-300 μ diameter. For smaller or larger droplets an increased total volume seems to be required to achieve the same effect, but the differences do not become great until very small (below 50 μ) or very large (above 800 μ) droplets are applied. If so, it would seem that efforts to reduce the size spread of the applied spray would be most rewarding.

When it comes to insecticides, however, the situation is more complex (Lawson and Uk, 1978). So much depends on where the insect pest resides and how mobile it is. Most estimates are that for agricultural purposes, droplets between 80 and 150 μ are probably desired, but there is contrary evidence that in some situations smaller (and more drift prone) droplets provide for the greatest efficacy.

The difficulty lies in producing a truly homogeneous droplet spray in sufficient volume to allow size relationships to be determined under field conditions. Accurate size distribution data is clearly lacking in fact for most nozzle systems that are presently in use, so that one cannot readily compare size-efficacy relationships for two quite divergent spectra. That ways to rectify this situation must be found and used is evident not only from efficacy uncertainties but from problems related to spray drift.

MONITORING AND CONTROLLING OFF-TARGET DRIFT

While it is true that most of the droplets produced in a pesticide spray application deposit within the target area, a small fraction does not. This fraction is known to be composed primarily of the smallest droplets, i.e. those having the smallest settling velocities and being most easily affected by turbulent air motions. Once these droplets remain airborne for even a few seconds, a further change occurs that makes further drift almost inevitable. This is the rapid loss of the water component, through evaporation; a 100 μ droplet containing 5% pesticide will shrink to only 40 μ or so before it can reach the ground from a wing tip vortex.

It is easy to define the target swath for groundrig applications, but less so for aircraft operations. In the latter the entire swath will be a few metres to one side (downwind) of the actual flight path, and will possess generally less-defined edges than does a groundrig swath. The deposit density will drop off rapidly with further downwind distance and it is common to define initial, or off-swath, drift as that droplet cloud still airborne some 2-5 metres beyond the expected swath edge. This, it should be emphasized, is not the same as "off-target" drift, except perhaps for the most downwind swath on a sprayed field. What happens to these airborne droplets subsequently is the primary drift control concern.

It is not sufficient to measure the spray output and the total deposit, in order to arrive at initial droplet drift by subtraction; measurement errors are nearly always too large to permit this approach. Direct measurement is required.

When this is done, the most significant observation is that the initial drift (e.g. at 5 metres downwind of the swath edge) is strongly correlated with wind speed. This is true even for groundrigs, which as might be expected, generally produce less initial drift than do aerial applications. As shown in Figure 2, the type of aircraft is also significant, with the faster, heavier ones giving rise to greater initial drift.

The subsequent behaviour of the initial drift cloud may be monitored as the droplets move off downwind. To obtain a full picture and to provide for a complete budget-type calculation it is necessary to sample both the ground-deposited material and that still remaining airborne at several distances. When such a field trial is analysed, it is possible to obtain a total spray picture such as Figure 3 illustrates.

It is also possible to show the rate of decay of the drifting cloud, as is done in Figure 4 (Maybank, Yoshida and Grover, 1978). Here the initial off-target drift amount is taken as the starting point. Had the fraction of that applied been used, the results for aircraft drift would have naturally been considerably greater since initial drift is some 10-20% of the applied amount compared to the the 1 to 3% for carefully operated groundrigs. What is noteworthy though is that the curve for the aircraft is steeper. This is because the initial droplet drift from aircraft is composed of a wider range of droplet sizes (including some relatively large ones of 100-200 μ) compared to that from groundrig application. The decay rate for such a droplet cloud would be expected to be faster. Again, as the distance downwind increases the influence of such properties as release height, wing tip vortex and aircraft speed diminishes and one is left with only the droplet size range (after evaporation) and the ambient air motions as factors. In short, the droplets can no longer be identified with the spray vehicle that released them and "drift is drift".

A further interesting feature of Figure 4 is the difference in decay rate between stable air conditions ("inversion") and unstable ones ("lapse"). This has been recognized by several researchers. Under very stable air flow, the drifting droplet cloud remains together as a thin layer and moves downwind as a significant potential hazard over considerable distances. Under light to moderate turbulence conditions, the droplets deposit out more readily and diffuse upward; both features contribute to a more rapid decrease in off-target droplet concentrations. Provided the ambient windspeeds are not too high when this condition prevails (e.g. mid-morning hours), one has the best situation for reducing off-target drift problems.

Direct measurements of off-target drift may now be compared with calculations that can be carried out on spray droplet clouds to identify how much goes where. The essential input components are droplet size spectra details, evaporation considerations, release height and aircraft turbulence, wind speed and atmospheric stability. Given each of these quantities one can obtain estimates for the amount of airborne material at various downwind distances and for the rate of droplet fallout. The results for a recent set of calculations is most revealing. According to Crabbe and Curry (1983), under typical wind and aircraft application conditions, the fraction of initial pesticide still airborne after 200 metres of downwind travel may vary between 0.1 and 40%, depending almost entirely on the type of nozzle, and hence droplet size distribution being emitted. These extremes may be compared with our measured data, of 5% of the initial drift as shown in Figure 4 (i.e. 1% of the total spray). Such calculations should show very clearly that there are spray equipment combinations presently in existence that can control off-target drift.

It should be emphasized that "zero" off-target drift is not a realistic goal. Rather, one should concentrate on reducing it to realistic and acceptable levels; most importantly one should know what amounts are drifting and to what distances as a first requirement. It should also be apparent that moves towards simply coarsening the spray are not particularly promising. Indeed, if they result, as many do, in worsening the deposit pattern uniformity within the target area, they may be counter-productive. Much better approaches are available and should be evaluated.

In the first place a more complete knowledge of the drop size efficacy relationship is required, for both herbicides and insecticides. With this information, one can proceed to narrow the emitted droplet spectrum appropriately, through design changes to the nozzle and boom system. As indicated earlier, the resulting distribution of droplet sizes must be carefully measured and characterized under typical operating conditions. Then nozzle placement and output can be adjusted to minimize the random variations in deposit density that are produced by the air turbulence regime. Once these problems are understood and accounted for, the off-target drift can be estimated for any given combination of atmospheric conditions and aircraft application factors. If the drift is acceptable in view of downwind hazards and off-set distances, one can proceed; if not, the operating conditions can be changed and/or an improvement in winds and turbulence regime awaited.

A final aspect of aerial application technology should be identified. This is the idea of ultra-low volume (ULV) application. Given that coarsening the spray is not by itself a promising approach to drift control, there can be little argument concerning the potential value of ULV. However, one factor encouraging off-target drift must be eliminated if ULV is to be an acceptable alternative. This is the rapid loss of droplet size through solvent evaporation. With ULV the droplet sizes will be already relatively small to provide effective coverage; further drop-size reduction must be avoided. This can be accomplished if the water component is replaced by an involatile (and safe) oil solvent. Future research into ULV clearly requires that such oil-pesticide mixtures be carefully investigated.

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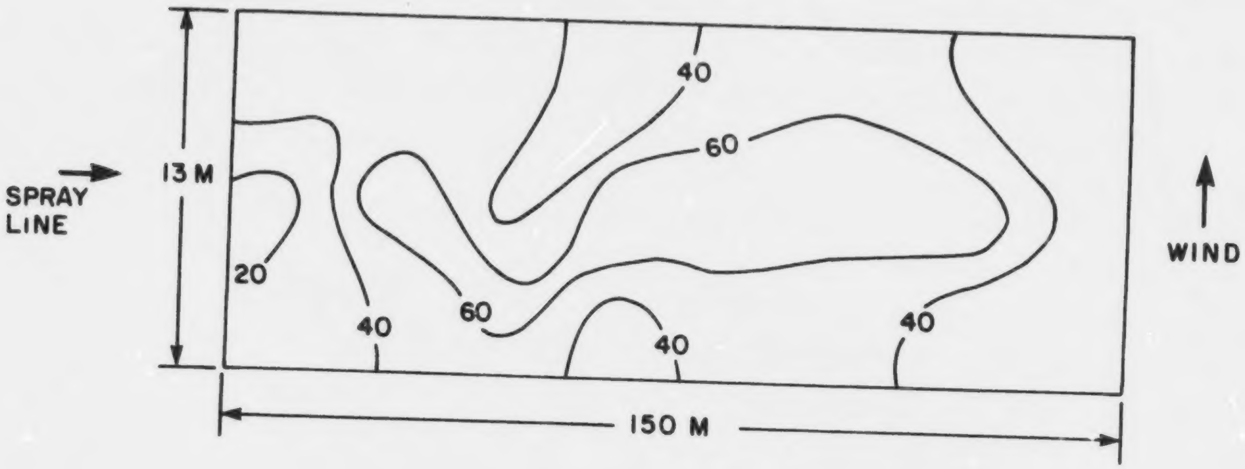
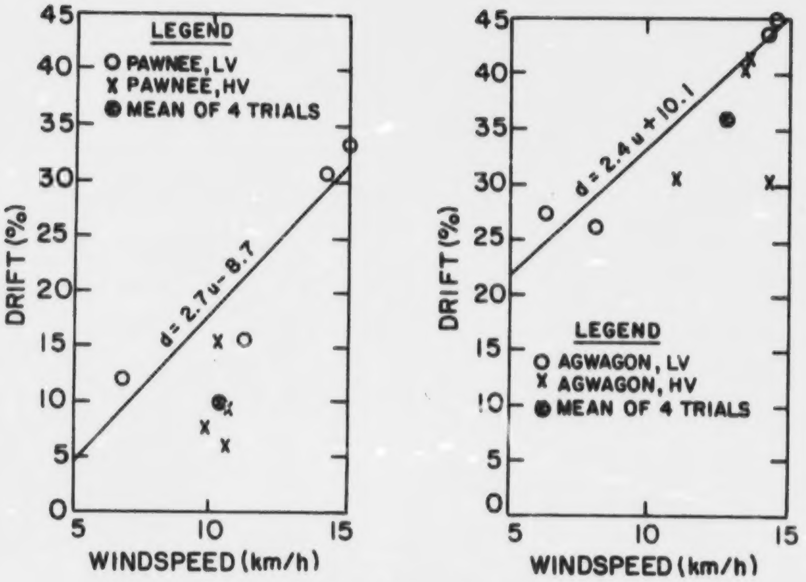
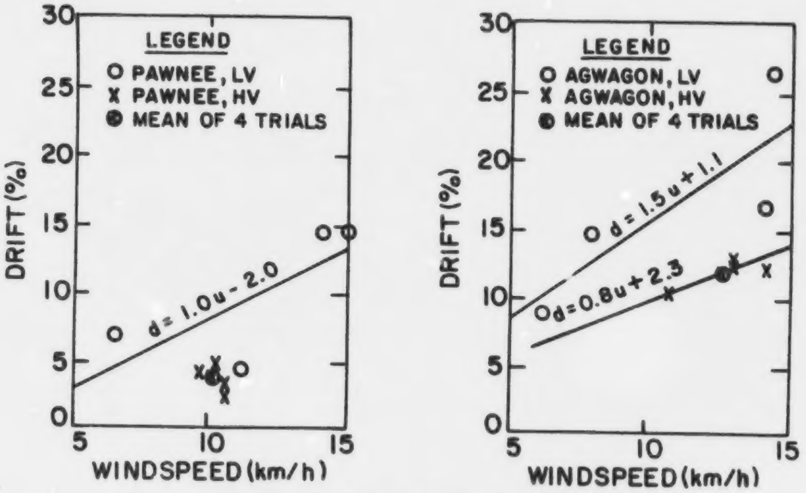

40
60
SPRAY LINE
13 M
20
40
60
40
40
WIND
150 M

Figure 1. A Typical Swath Deposit Pattern (mg/m^2)

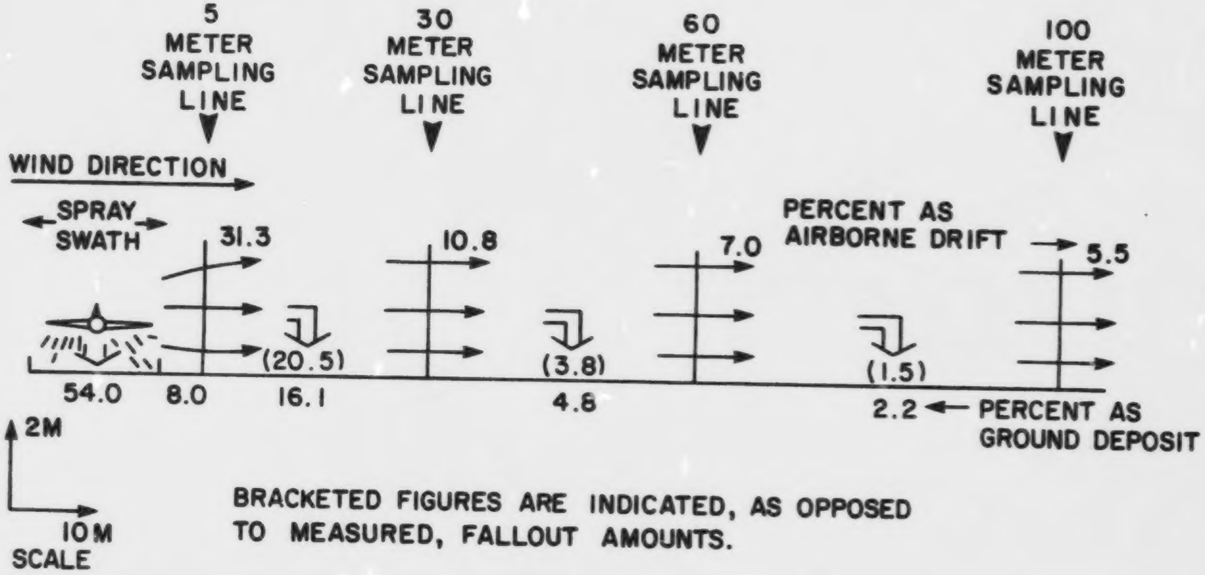


a) AT 5 METER LINE



b) AT 30 METER LINE

Figure 2. Initial drift from several aircraft


5 METER SAMPLING LINE
30 METER SAMPLING LINE
60 METER SAMPLING LINE
100 METER SAMPLING LINE
WIND DIRECTION
SPRAY SWATH
31.3
10.8
7.0
PERCENT AS AIRBORNE DRIFT
5.5
(20.5)
(3.8)
(1.5)
54.0
8.0
16.1
4.6
2.2
PERCENT AS GROUND DEPOSIT
2M
10M
SCALE

BRACKETED FIGURES ARE INDICATED, AS OPPOSED TO MEASURED, FALLOUT AMOUNTS.

Figure 3. Schematic Diagram of the Aerial Spray Mass Budget

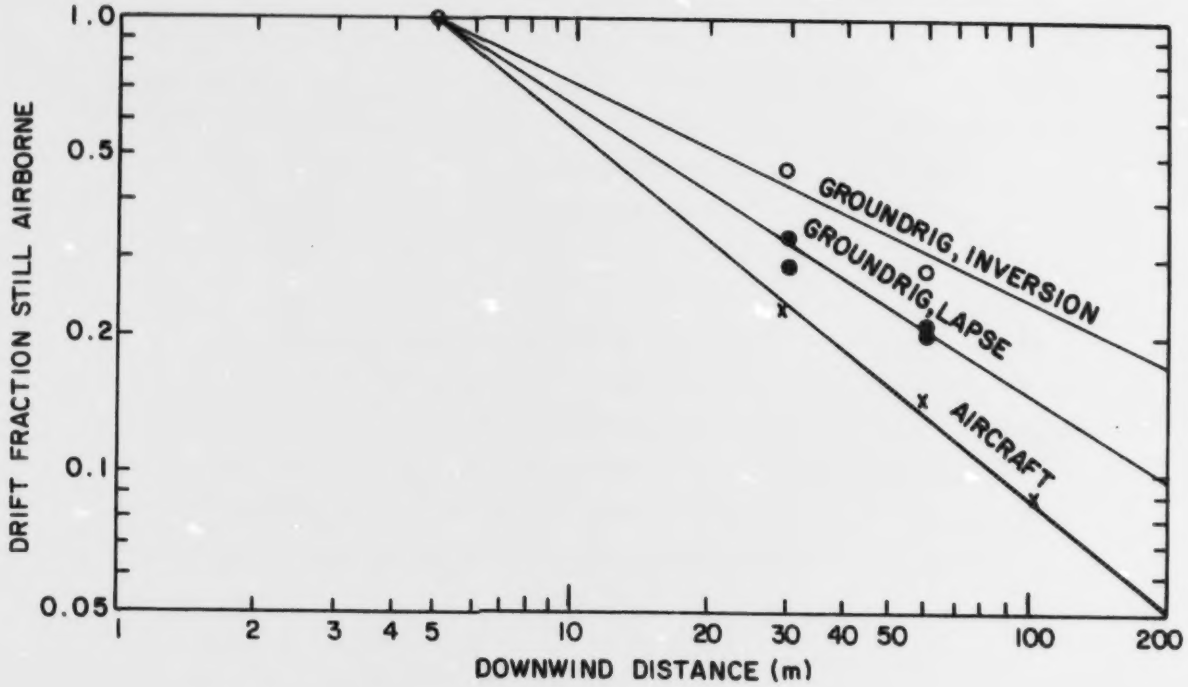


Figure 4. Decrease in Droplet Drift with Downwind Distance

Paper No. VI-B

THE COMMERCIAL OPERATOR

W.F. Keith
Quikway Aviation Ltd.
Box 1700
Brooks, Alberta
TOJ 0J0

From 1954 until the present, the period of my involvement in the industry, the operation and management of an aerial application company has progressed from a pencil and notebook in the shirt pocket to the present day use of computers, chemical experts, certified accountants, district agriculturalists, government horticulturists and experimental personnel, medical doctors, environmentalists and a friendly bank manager.

Equipment too has changed from what are considered today as vintage aircraft like the Tiger Moth, Stearman and Lysander, in fact everything that could fly, to the present day aircraft that is specifically designed and manufactured for the purpose. Bigger and better engines including turbines are being used. Design of spray booms and dry material spreaders have also gone through some changes.

PRESENT SITUATIONS & DEVELOPMENT

Present situations demand well-trained business-like personnel, gone are the old images of the barn stormer types. The present day well-run aerial agricultural company in a great many areas throughout the world, has become a very essential part of the agricultural and forestry scene. The ongoing development of aircraft and equipment will only increase this usefulness. To give you an idea of the type of work that is being done, my company for instance is involved in:

1) Liquid spray applications for pest control involving 40 or more types of chemicals in (from 1 to 15 gallons) of water to the acre.
2) We do a lot of seeding by air including alfalfa, canola, mustard, grass seed, wheat, barley and oats.
3) Seeding and fertilizing pipeline right-of-ways, well sites and mining operations.
4) Defoliating seed alfalfa, canola, flax, peas and potatoes.
5) Weed control of canals and ditch banks.
6) Algae control in sloughs and dugouts etc.
7) Range patrols in our own rural crime watch areas.
8) This year the local rural fire department is organizing a fire retardant operation with the use of our aircraft.

So you see the uses of agricultural aircraft are quite varied and I believe their usefulness as a farm and forestry implement has just started in Canada. We are behind in some respects, hopefully meetings like this will put us on a level with New Zealand and others.

FUTURE CONCERNS

(1) Public relations and education is needed because of the highly visible and somewhat spectacular aspect of the helicopter and fixed wing aircraft when they are spraying. The public relations with all concerned has to be thorough. I have found that explaining the operation to the local RCMP and all concerned can be very helpful. The industry needs more exposure through chemical companies and the Government agencies to help in this part of an operation. A big concern that is difficult to handle is the ever-growing number of urbanites moving to live on small acreages in the farming

community. The agricultural industry as a whole has to try and make these people aware of the necessity for motors running 24 hours a day, manure being put on fields with sometimes not the most pleasant odors and farm machinery moving around, including aircraft.

(2) Dealing with Government agencies is becoming more difficult. There has to be more input accepted from the operators. I will say that the Alberta Department of Environment is getting better at asking for advice and input. But is it enough?

The Department of Transport will have to recognize that we are not airline companies and parts of the regulations do create hardships. We all recognize the need for regulation, but to help, not hinder.

In Alberta there are some very knowledgeable operators that have worked in many different parts of the world, and if their advice is used, this expertise could add a tremendous amount to the orderly development of the industry.

(3) The future needs for training and trained personnel can easily be handled by the individual operator. In most cases this is preferred, because of the great expense of training pilots. Some job creation assistance would be very helpful. To my knowledge there has never been a successfully run agricultural training school other than the training done by an established operator working on the old apprenticeship idea.

(4) Other concerns, like the difference between the status of the flying farmer and the commercial operator will have to be addressed in the future. It can create unfair competition in

some areas. The industry is faced with high insurance rates because federal regulations limit access to the Canadian brokers whereas cheaper rates are available on the U.S. market.

I would guess that the list could go on and hopefully from this point on, the aerial agricultural industry will be looked at as a necessary and useful agricultural and forestry tool by the Government agencies involved. With help and direction from all concerned and a reasonable approach from our bureaucratic system, this can be obtained.

Paper No. VI-C

THE FARMER AS A CUSTOMER OF CUSTOM AERIAL SPRAY SERVICES

Glenn E. Peterson
Box 25
Cardross, Saskatchewan
SOH OPO

ABSTRACT

This paper provides some views of a farmer who contracts for a commercial spray operator's services. In the early days ground spray rigs were used because that was all that was available. However, the machinery was inefficient and generally did an unsatisfactory job. When chemical herbicides were introduced (2,4D), farmers had to go through a learning process, errors were made, but the impact on crop production was dramatic. Aerial spraying has solved a lot of problems, particularly timeliness. However, this has come about through an evolutionary process. Today aerial spraying is an integral part of farm operations. To be successful the farmer must investigate to assure himself that he is hiring a responsible operator who has the knowledge, experience, skills and equipment to do the job. The farmer must plan the operation and ensure proper liaison is maintained with the operator and chemical company. Experience shows that aerial spraying is effective on the farm.

Early Ground Spraying

In the early days, there was no other choice but to use ground spray rigs. Equipment was in short supply. Sprayers with short booms, poor type nozzles, with limited adjustments for height and pattern resulted in poor, uneven spraying. Farmers would collaborate to purchase a sprayer but as a result, the last farmer's weeds were too far advanced to get a proper kill.

Some boomless sprayers came on the market. These caused a number of problems:

Burned crop from overlap;

Drift from lack of knowledge and careless use resulted;

Some farmers took advantage of the wind to get a wider swath resulting in the loss of trees, clover fields and gardens.

Early Chemicals

When 2,4D came into use in our district, it was the first step toward changing the colour of fields from mustard yellow to crop green. Few farmers knew the meaning of fluid ounces or calibration. Therefore, in some cases too much chemical was applied, in other cases, too little. Few farmers complained as they hesitated to let their neighbours realize their lack of knowledge. The chemical company was usually the one to get the blame, ("when all else fails, read the directions").

Weather Conditions

In the early days of spraying, weather always seemed to be a problem. You would move equipment to the far farm, it would get windy or rain, with the field half done. You would drive the tractor home, leave the sprayer, "planning to come back tomorrow." Four days later you returned, thinking: "maybe I can finish it now." However, the neighbour's pigs had chewed the hoses off the sprayer! No chemical left, so to heck with it, the weeds are too far advanced anyway. Muddy fields caused problems. "I got the tractor out but couldn't dig out the sprayer", was a familiar story. A lot of crop was tramped down due to the mud also.

Misuse of Chemicals

It was quite common years ago to spray road allowances with trees in the background. Gardens also took a great loss. Even the fumes would kill tomatoes and beans. Chemical pails were left lying around due to people not realizing the danger.

Aircraft Spraying

When first introduced, crop spraying by aircraft seemed to solve a lot of problems. You must first shop around for the right operators.

Responsible Operator

He must have a wide knowledge of the different chemicals. We now have chemicals and insecticides with varying degrees of potency (toxicity). Most spray operators spend much time familiarizing themselves with these new substances to improve their operations.

His experience is important. Ask if he has done this kind of application before, find out all you can about the operation, where he previously used the chemical, and its effectiveness. The main question is, is he dependable?

Efficient Equipment

Make sure the aircraft is equipped with proper booms and nozzles to apply the correct amount of chemical per hectare. Question the operator as to the spray pattern and aircraft speed he will use.

Proper Timing of Application

Don't let the weeds get ahead of you. Be sure your operator knows the proper plant size or leaf stage at which the chemical should be applied. Be certain the day is not too hot. Hot air rises carrying the chemicals, and evaporation will not kill weeds. Pick an early morning or evening. It takes a very short time to spray a 50 hectare field. Let the wind drop and the air cool, you will still have plenty of daylight.

Advantages of Aerial Application

From my experience with aerial spraying for over twenty years, I would like to give you my point of view of this service. Time saving is important for spraying as well as other farm chores. There is a time for every farm job, don't put off spraying until weather and field conditions put you into a rushed period resulting in a poor job and taking risks. If it has rained the night before, spraying can still go on and based on my experience, has some advantages: growing conditions are right and these give the chemical a fair chance; humidity is high; plants are moist, not dry and brittle; the air is cool and there is likely no wind. So hit it early!

Liaison between Applicator and Chemical Company Dealer

The spray operator makes large purchases of chemicals, usually by the barrel. He does not go down to the farm supply store for a few litres at a time. He has discussed the chemical question with his supplier and knows what he needs for the job. Because the spray operator buys early in large amounts, the prices are lower and the farmer usually gets the benefit. The operator often has field men from the chemical company out to evaluate the chemical and to see if any improvements can be made. Local purchasers seldom see anyone but the store clerk who is not required to do anything but sell the brand at a price from the book. A majority of farmers don't know if it is a fair deal or not.

Toxic Chemical Application by Aircraft

There is just no argument here from a farmer's viewpoint. Air spraying for grasshoppers or cutworms is much safer than sitting on a tractor breathing toxic fumes, for hours at a time. As for coverage, all sloughs, fencelines, rock piles and road allowances are sprayed where wheeled equipment cannot go. This applies to herbicides as well as dangerous insecticides.

In my opinion we should encourage the use of the airplane to control weeds that are slowly taking over our roads, fences and sloughs, such as Canada thistle, Sow thistle and Bind weed.

I would also like to suggest we eliminate some hazards such as telephone pedestals painted green in a wheat field and tap lines that are not marked.

In closing, I mentioned sloughs, and in my farm operation, a slough is a portion of my field that is seeded and the next day gets flooded out, covered with ducks, spreading seeds from Canada thistle or Sow thistle, etc. into the slough area. A water hole or a pond is altogether different. We're not going to let any spray operator go out there and put expensive chemicals on a water development that doesn't require it, but a slough is different. We need to rebut the environmentalists who say the farmers are out there spraying all the sloughs and killing all the vegetation that keep the ducks healthy.

Paper No.VI-A

THE FARMER AS AN OPERATOR

Carl Gillis
Box 45
Gray, Saskatchewan
SOG 2A0

ABSTRACT

As a farmer operator, aerial spraying provides me with a means of applying chemical treatment to crops under any soil conditions, a definite advantage for timeliness within our short growing season. My concerns include:

- the over-regulation imposed by the Ministry of Transport regarding airworthiness;
- the real and imagined drift from aerial spray applications and the fact that often aerial applications become the scapegoat for drift from ground spraying;
- the lack of information;
- available equipment is not suitable for Canadian conditions.

For the future, I envisage increased use of aircraft for seeding into standing crops before harvest and the application of urea fertilizer on snow in the spring.

AIRCRAFT ARE THE BEST METHOD OF APPLICATION

When I got out of the R.C.A.F. and started farming I had a commercial aircraft operator do my spraying. I owned neither a field sprayer nor an aircraft. I then bought a field of sprayer as I felt I could do it cheaper and just as well myself. I used a field sprayer three years and then went back to having a commercial aerial applicator do my spraying. Although initially it appeared to be more costly I felt I was getting a better job of spraying than with a ground rig even though I was using five gallons per acre with the ground rig and the aerial applicator was using half a gallon per acre. I then bought a ten year old Cessna 172 and a year later put an old Sorenson spray rig on it and sold my ground sprayer.

I am totally convinced in my operations that a ground rig simply can't do as good a job as an aircraft.

I farm in fairly flat country and the only trees we have are shelter belts around the yards. The main obstruction to aircraft are power lines. You have to work around the power lines with an aircraft but field sprayers have to work around the power line pylons and they also have to work around or through our sloughs. To work around a slough with a field sprayer you must either overlap or miss while the aircraft can proceed across the slough. I've seen many times where ground rigs have tried unsuccessfully to cross some of these low spots. They don't do a very good job if field conditions aren't ideal.

The aircraft allows me to be very timely in my application of chemicals because I need only worry about crop conditions not field conditions. I sprayed many acres last year when you couldn't walk in the fields, much less drive a ground rig of any type. The crops may have been under some stress due to too much water but the end result at harvest showed the sprayed fields to be better than those that had not been sprayed for weeds.

On my own farm I have done quite a lot of spot treatment for both Canada thistle and wild oats. I find spot treatment for wild oats is only possible when spraying long fields that are seeded straight back and forth. In a year when you have seeded around a lot of sloughs you can't discriminate the wild oat patches within the cross seeded crop but when the drill rows are straight it is quite easy to see the oats between the drill rows.

I have flown a friends aircraft and sprayed grasshoppers for him, a problem we haven't had at home. He will spend several hours touring in his half ton checking his potential trouble spots next to his grassland or along road ditches then a half hour of flying will catch all the hot spots even though they are spread over ten or twelve miles by road. By spraying quickly he can keep his damage to about nil. With the airplane you can do it again in a week or ten days if you were premature with the treatment. Moving a ground sprayer around to do this would be very time consuming and frustrating which could well lead to ignoring the problem until it becomes a major outbreak.

As I've said we can work when the crop is ready to be sprayed. We don't have to worry about soil compaction. Last year we sprayed several thousand acres when I could hardly get out of the yard with a load and the spray coupes or floaters couldn't move at all in the fields. It wasn't soil compaction that was the problem they simply couldn't move and my flagmen walked the high roads where possible.

We work only from our farm yard. Flying Farmers by law are restricted to a 25 miles radius but we generally stay within ten or twelve miles. To transport farther we would have to charge extra because of the increased ferry time.

By working only from the yard we don't need the extra equipment or manpower which a chemical and water truck would require. Since we are working from the yard there does not seem to be that urgency to apply that "one last load" even though the wind or weather isn't right. Equipment does not have to be moved to another location for the next day's spraying. Another factor is that if it gets a little breezy you can always switch over to some other job on the farm. If you were away from home there could be a tendency to press on when conditions aren't perfect. Thus I can allways use my own time efficiently.

We do our own swath marking for our farm but when doing custom work the farmer supplies the flagmen. We supply them with the measuring equipment. Its not very high technology, but it is very high on accuracy. Our measuring device is nothing more than a measured length of 3/8 inch poly rope on a two gallon jug.

I am a strong believer in accurate measurement for marking. We don't just pace it off on our own farm and I wouldn't want to do custom work for some one else without accurate measurement. What was good enough for old chemicals is certainly not good enough for newer more expensive chemicals. Although there are some agricultural pilots with an uncanny ability to eyeball the right swath width, I can't do it. When I speak of marking I am talking about weed sprays. I also try and keep my markers just outside the field although this occassionally isn't possible but if you are moving across the field into the breeze they should be clear of any spray contact.

For spraying insecticides for flea beetles or grasshoppers I do not have any flagman in the field at all but instead use the T P flags, without the perforations. Measuring for insecticides is done by "guesstimate" from the cockpit.

I like the farmer to do his own marking for his crop because then he knows the exact stage the crop is in when sprayed and the exact weather conditions. If he doesn't have enough interest in his crop to be there when it's sprayed I wouldn't have much interest in spraying for him.

We generally use the chemicals of the farmers own choosing but last year when the weather turned extremely hot we talked some people out of using Banvel for instance or else sprayed it only on the first field in the morning. In some cases we have also talked them into using less that a maximum rate if the crop could be under some stress.

Concerns

I have a number of concerns regarding aerial application and the order I present them in doesn't necessarily indicate their relative importance to me.

Ministry of Transport (MOT)

My first concern is with MOT and their regulations. When I left the R.C.A.F. I believed that almost all regulations were there simply for flight safety. Today I would be very happy if this were the case. Today, especially since the Dubbin Commission, there appears to be a lot of empire building going on (Enforcement Branch) and a fair bit of what they called in the Airforce "cover your ass". I worked for a fellow in the airforce that believed if enough regulations were written he had done his job and was fire proof. This seems to be MOT's policy today.

To illustrate, I had an accident about two years ago, a mid-air collision with a power pole. By The Grace of God and a little airfighting and aerobatic experience I didn't hit the ground. I flew the aircraft back home and reported it to MOT. I was a little surprised when three months later I was charged with operating an aircraft in a negligent manner. MOT did not come to the farm to view the aircraft, did not view the scene of the accident or talk to me (the pilot). I spent $2,118 for a lawyer and nine months later they decided they did not have a case and dropped the charge. Unfortunately a private citizen cannot sue the crown. That's my feeling on some of the flying regulations and the enforcement branch regarding crop spraying. They know nothing about crop spraying but hate to admit it.

There is a definite move to try and put a calendar and hour life on many components where the manufacturer has indicated a "recommendation" for overhaul. The manufacturers "recommendation" is only just that in the U.S.A. but MOT is striving to make it a compulsory item. I wish they would check the dictionary for the meaning of "recommendation".

The MOT lost an aircraft of their own due to airframe breakup. This aircraft was operated overloaded and also was operated most of its time at a low level when it was not designed for that task. Their reasoning from the accident was that since all spray aircraft operate at a low level they should have a definite time life established for main wing spars. Yet these aircraft were designed to work at a low level all their life and to haul the loads involved. Because of the nature of agricultural aerial application, the aircraft are subjected to turbulence for only a very small fraction of their flying time. When the air gets rough it's not good application weather so the operation stops.

If Department of Agriculture really believes in aerial application they should make certain that MOT keeps their regulations realistic. All aircraft accidents can be prevented by keeping the aircraft tied down but that doesn't produce results. It's strange that Agricultural aircraft in the U.S.A. fly many times the hours of those in Canada yet MOT think that the Canadian registered aircraft require extra servicing or a reduced life span for components.

Drift

Drift is the question that worries me most when doing spray work. I have never seen any real research done on the subject, the amount of Canadian research done on aerial application I suspect wouldn't make a story for the Readers Digest. What I know about drift has been picked up "piece meal" from other operators and from the meteorogical knowledge I gained in the R.C.A.F. Most people think drift is a problem only when it's windy. In fact some of the worst drift conditions can occur when it's almost dead calm combined with a shallow inversion. Most farmers do not know what an inversion is, although they have seen the effects many times. It's visually apparent in early evening where the dust behind the harrow hangs in the air while you make another pass across the field. The air is warmer aloft and cooler at ground level, the warmer air rising tends to keep dust particles or spray particles suspended for a long time. Some of the worst drift can then occur under what may seem like ideal spraying conditions. This is not restricted to aerial rigs as I have observed it personally with field sprayers.

An outside air temperature gauge in a spray aircraft and a smoker are the two best aids in keeping track of drift and excess drift. The outside air temperature gauge lets you check for inversions. At this point I should thank Dupont for bringing the Oklahoma State University equipment to Canada to aid in pattern correction for aircraft. It's the first real attempt I know of by any agency, government or private, to assist the aerial applicator in Canada. If the application pattern is controlled better, then drift is also better controlled.

The risk of drift with an aircraft may be greater, but drift from ground sprayers is often totally ignored. That frightens me as an aerial applicator because the guy that makes the most noise gets the blame.

I would suggest that anyone investigating a drift problem should make certain they investigate thoroughly. I flew Department of Agriculture people last year to take pictures of a drift killed field, in all likelihood caused by an aircraft. I don't know where the situation stands legally so won't touch on it further. I just want to point out that I do know aircraft can cause severe problems. A personal experience illustrates the kinds of situations that often arise. I was told that when I sprayed next to town that they could smell weed spray in town. After talking to the individual concerned I suggested where he might find the real source. One individual in town likes to spray his yard in the evening with a hand sprayer. When I suggested this, the person who thought I had allowed spray to drift into the town, said the damage got worse the closer you got to the source I had suggested. All the drift would have been downwind from my suspect. I had used the smoker regularly that evening and the marker flags always showed a positive air flow away from town, yet because my aircraft was the most visible spray operation I was assumed to be the culprit.

I know aircraft spray drift will kill but so will drift from a field sprayer or a hand sprayer. I keep track of all ground spraying around home that I observe if drift conditions seem likely. I have been able to follow bad examples of ground spraying for two miles from the smell of the chemical. I keep track of these potential drift problems - date, time, weather, etc. in case I, "the noisy kid" on the block, become the scapegoat for problems generated by a ground rig.

Don't get me wrong on one occasion I know for certain that I cut a swath into a neighbor's field. I was flying a friend's airplane and his shut off valve worked reverse to mine and I goofed. The neighbor accepted my apology and fortunately the crop recovered pretty well. By the same token I have seen a couple of acres of flax taken off a field by a field sprayer's drift and there was no apology, in fact no acknowledgement that it ever happened. I have many similar stories. One pilot I know was seeding a late field of rape for a fellow a quarter of a mile from a yard. Three days later the farmer came to tell him he was going to sue him for killing his trees and garden. A dripping field sprayer in the yard with 2-4D Ester in the tank seemed to be the more likely candiate than the rapeseed the plane had spread.

We must control drift because if we don't we'll be sued or legislated out of business. Maybe not just the aircraft but the chemicals as well.

Equipment

I am concerned also about the equipment we use. My "old bird" nineteen years old, is the smallest special spray plane built and I believe the first special agricultural type built. Since then aircraft have gone up in size and HP continuously.

The problem is the short utilization season in Canada cannot justify the large expensive aircraft. The cheapest new aircraft is I believe a Cessna Ag Truck - $97,800 U.S. or about $123,228 Canadian (at 26% exchange). Flight insurance could be $12,000 a year. You would have to be a magician, not a pilot, to make a living in our short Canadian season with the overhead from a machine like that. We are therefore going to see the majority of work done with older aircraft and we must impress on MOT that unnecessary maintenance or overhaul requirements will kill aerial agricultural work. Unnecessary overhaul cannot be passed on to the customer. The government can pass on increased costs to the taxpayer indefinitely but the farmer customer cannot pass his costs on since he is a price taker not a price setter for his products.

In order to make new, bigger, more expensive aircraft pay we must hit more than insects and weeds in a three or four week season. Alberta, I know makes more use of aircraft by spreading fertilizer by air but deep banding may prove so much better than spreading that this could be a lost job for aircraft in the future.

Future Uses

Perhaps if urea was spread on the snow in late spring the extra day or two gained by early snow removal would offset the difference between deep banding and spreading. I've never done it, but this is just a thought for the researchers and the operators that are now doing aerial spreading.

In order to keep an airplane working we must do things better than other equipment or do things other equipment can't do.

In the U.S.A. they are working at spreading winter wheat into standing soybeans before harvest. Some farmers have had excellent success. When the soybean leaves fall they provide the cover for the wheat and the soil is not worked in any way. There could be similar situations with certain crops in some areas of Canada.

In conclusion, the airplane has to do a job better or cheaper or do something no other machine can do or it won't be used in agriculture.

Paper No. VII-A

THE DOLLARS AND SENSE OF AERIAL SEEDING AND GRANULAR APPLICATIONS

Ken H. Scheske
President
Russell Air Services Ltd.
Russell, Manitoba
R0J 1W0

ABSTRACT

The use of aircraft for applying seed, chemicals in granular form and fertilizer is discussed. Many farmers are adopting the services of professional applicators to advantage. The market is showing steady growth and there is a large potential market in pasture development. There is also a large future market in reforestation projects. It is concluded that these operations utilizing aircraft will continue to expand.

INTRODUCTION

I have titled my presentation, "The Dollars and Sense of Aerial Seeding and Granular Application" for a number of reasons.

Aerial seeding and granular application in Canada is a fairly new field, largely adopted from our American neighbours, using American-made aircraft and spreaders. By adapting them to our own unique market, seeding and granular application is becoming more common place each year. Of all the aerial applicators I am acquainted with, most have at least one spreader and count on part of their season for seeding and granular applications in their business plans.

The following explains how we apply either seed or granular material, which I'll call the product, by air. First, as in any farming operation, time is money and therefore the less time spent on the ground loading the aircraft, the more hectares that can be covered. In order to accomplish loading quickly and efficiently, the operator should have a ground crew and an adequate loading device, be it a conventional loader or a boom truck so that the turn-around time is minimized. Once airborne, the pilot will fly to the field, scout it and then commence the operation. Normally, when applying a liquid product, the pilot will fly quite low over the target area. However when seeding or applying granular material, the aircraft will be flying at a height of 10-15 m above the target area. This assures an even distribution of the product, and as drift is minimal, the pilot is comfortable at this height. The number of hectares covered per load is dependent on the different products.

Aerial Seeding

Some types of seed are better suited for aerial application. The aircraft's major restriction is the small amount of weight it can carry. Thus seeds that require the least weight per hectare are the ones best suited for aerial application. Therefore, if a typical aircraft (e.g. 188-B Cessna AgTruck) has a load capacity of 680 kg in the hopper, then seeding Canola at 5 $kg \cdot ha^{-1}$ would enable the pilot to take off with a 70 ha load and still be well under the aircraft weight limitations. On the other hand, in seeding wheat by air at 135 $kg \cdot ha^{-1}$, flights would be restricted to 5 ha loads. Such loads are not economically feasible unless the airstrip is beside the field. Therefore, the most common types of seed aerially applied are Canola at 4 to 9 $kg \cdot ha^{-1}$, all types of grass and forage seed, from 2 to 11 $kg \cdot ha^{-1}$ and flax at 22 to 34 $kg \cdot ha^{-1}$.

There are many other types of seed; however, the same governing factors will apply for aerial applications:

1) the number of $kg \cdot ha^{-1}$ required;
2) a proper method of incorporation to ensure good even germination after seeding.

The advantages of aerial seeding relate to time and weather, especially in a late wet spring. By aerially applying the seed the farmer saves a lot of time in the seeding operation itself; 40 hectares seeded per hour is normal. Subsequently he need only incorporate the seed by harrowing and packing. By using the aircraft, it is very easy for a farmer to have a half section seeded and incorporated in the same day.

As farming operations across the Prairies become larger, the aerial applicator is finding an increasing market for this operation. The farmer does not have the time to complete his seeding operation by himself.

One other application where timing is of utmost importance is when seeding grass or forage seed into a standing nurse crop. The best time to seed this crop is right after the nurse crop has been weed-sprayed and the crop canopy provides enough protection for the moisture in the seedbed. Once the forage crop has caught you know you will have a good clean forage crop for years to come. How else could the farmer do this without the aircraft? If he were to use ground equipment, the resultant damage to the nurse crop would far outweigh the cost of the aircraft operation.

In any aerial application situation, the weather has three very important variables which the aerial applicator must be constantly aware of: 1) wind; 2) barometric pressure, and 3) air temperature. However, when it comes to seeding, these variables are not so much of a concern. In spraying situations, drift is a main concern, whereas in a seeding situation, one can seed in steady winds from 0 to 5 $km \cdot h^{-1}$ with virtually no worry about drift. As long as the pilot works in a steady crosswind, seeding remains uniform throughout the operation.

Barometric pressure and air temperature seldom affect the seeding operation except in extreme cases. Therefore, the farmer and the pilot can remain comfortable in a variety of weather conditions and still get the job done satisfactorily in a short time.

The key condition for aerial seeding is soil moisture. In most aerial seeding operations, the seed is either left on top of the seedbed, as with grassy seeds, or incorporated to a very shallow depth by harrowing and packing (e.g. Canola and Flax). Without adequate soil moisture, the soil could dry out before the seed has a chance to germinate and root. However, on the other hand, too much moisture is just as bad. In a situation where the land is too wet the farmer will not be able to get on the land in a reasonable length of time to incorporate the seed and might just as well not apply the seed. Therefore, the correct moisture level in the soil is the governing factor for aerial seeding.

An important aerial seeding operation involves converting near useless land into productive pasture. Take a situation where trees, very uneven and/or rocky terrain, limit utilization of the land. To bring a Caterpillar or any ground equipment into such an area would be too costly.

By using the aircraft, we can turn a costly operation into a profitable one. First chemicals are applied by aerial spraying to defoliate the trees and brush which are targeted. A double application is used, preferably over a three-year period. Then as the trees and brush die, grass and forage seed can be aerially applied under the right conditions. This seed will grow now that the tree and brush canopy are gone and convert the land into productive pasture. The cattle seem to do the rest of the job as they forage for feed, by gradually destroying the resultant deadfall. There are community and public pastures all across the Prairies which prove this method of farming by air.

In Canada, over the last century, we have been steadily depleting our forests. Only recently have governments or private companies come to grips with the situation. Unless we start a massive reforestation program, we will deplete this vital natural resource. Here, the aircraft with its spreader (or seeder) will play a vital role. From the work and data gathered to date, it appears aircraft will be able to fill the role as the important factors governing aerial seeding are easily met: 1) the weight of seed to be applied per hectare is small and, 2) the moisture levels required in the vast amounts of land to be reforested can easily be monitored, met, and then seeding done at the proper time. There are millions of hectares to be reseeded as a result of fires, pests such as the spruce budworm, acid rain, and also regular logging operations.

Granular Applications

For granular application by aircraft, we use exactly the same spreader as for seeding operations. Thus problems resulting from changing over equipment do not arise. There are several farm chemical products on the market at this time, licenced for aerial application, and apparently there are more on the way.

For aerial application of farm chemicals, there are basically only two seasons for this work; either in the spring, before or after seeding, or in the fall, after the harvest is completed. The chemicals which are on the market today, seem best applied in the fall for several reasons: 1) the farmer has adequate time to plan his application program; 2) the products incorporated in fall seem to do a better job as they have more time to move in the soil; 3) the days are crisp and clear and it is really a pleasure doing your job under these conditions, and 4) the more work done in the fall, the less rushed the operator and the farmer will be in spring when everything seems to be happening at the same time.

Again, as with seeding, weight and hectares to be treated are important. Products requiring 35 $kg \cdot ha^{-1}$ or less are suitable for aerial application. Granular products applied in the spring or fall must be incorporated in order to be effective. Therefore drift of the products is not a problem, as they become inert when left on the soil surface.

The aircraft can also apply fertilizer and with the many new types and blends coming into use, the aircraft seems to be finding an expanding market here. However, most conventional fertilizers where rates of 50 to 250 $kg \cdot ha^{-1}$ are required, still restrict the use of aircraft in this application because of load limitations.

The Current Situation

In today's market aerial application is becoming a widely accepted method of custom farming. The farmer is including the cost of aerial application in his long term planning and budgeting. This was not the case previously, where the aerial applicator was only called in as a last resort to save a crop from some natural disaster or pest. Consequently, aerial applicators today are not a wandering breed looking for work wherever they can find it. Across this country, local professional applicators are serving their communities. The farmer can depend on a professional providing services at a fair price. The aerial applicator has become a custom farming service just like any other that the farmer has come to depend upon in today's expanding market. The reason the applicators exist is that they are cost-efficient.

Timing and weather always play an important part in farming operations. It is here that the aircraft shines because of the large areas it can cover in a short period of time. The old saying that "you don't have your crop until it's in the bin" certainly applies here. The aircraft may give the farmer those few precious extra days needed to produce a crop in Canada's short growing season.

CONCLUSION

I have dealt only briefly with the areas of aerial seeding and granular application which are familar to me to illustrate the potential. With rising costs for machinery, fuel, labour and farm materials, the aircraft will continue to be a viable and cost efficient tool for aerial seeding and granular application. What we are finding in today's market is that customers use our services every year, we depend on them and they on us. Aerial operators do a certain percentage of a farmer's work every year. The reason this is happening is not only the savings in time, but also money. In present tight economic times, the farmer above all others sees all of his costs rising, but the price for his product remaining virtually the same. Thus the farmer should be the best judge of the effectiveness of aerial applications.

There are more hectares covered and more aircraft involved in aerial application every year across the country, and these figures speak loud and clear. Aerial applicators are professionals and they are here to stay.

Paper No. VII-B

AERIAL SURVEYING AND REMOTE SENSING

A.R. Mack
Land Resource Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario K1A 0C6

ABSTRACT

Aircraft and satellites provide a base for carrying a variety of data collection systems to provide information varying in frequency of coverage and spatial resolution. These vary from the small remotely controlled "model" aircraft which fly immediately above a crop to aircraft covering 100 square miles in one image. Video camera systems are being developed to complement 35-mm and 70-mm camera systems for local field use and for providing farm records of poorly applied herbicides and fertilizers. Where repetitive historical coverage is required of a region for determining changing land-use patterns, Landsat satellite data at a scale of 4 miles to the inch (1:250,000) is becoming available for the period 1973 to 1983. Recently data from U.S. meteorological satellite systems have become available for daily coverage of a large region (e.g. a province) at a scale of 1:5,000,000 for quick location of highly productive and drought stricken vegetative patterns.

Traditionally aerial surveying has been used for appraising Canada's land resources and classifying their physical capabilities. Photographic systems using black and white imagery were used in the 1930's and 1940's for toposurvey and land-use mapping of agricultural and forestry areas (14)*. In the 1950's, the introduction of airborne color and infra-red color film offered a wider range of specialized applications particularly for assessing vegetation (6). Greater emphasis was placed on the quality of spectral properties of the photo than was required previously for survey mapping. Several camera sizes were available: (1) the large 230 mm precision metric cameras used for large scale surveying, (2) the 70 mm and, (3) the 35 mm. Excellent quality lenses were available for the three sizes and high quality images were possible. The smaller cameras were ideally suited for small aircraft.

Special training, however, is required for assessing crops particularly with infra-red color film. The film is sensitive to the reflection of green, red and infra-red (IR) from the plants. Healthly crops absorb the red radiation (Chlorophyl) and reflect highly the near IR. Unhealthy or stressed plants produce the opposite effects. Infra-red film requires cold storage (<0°C), purchase in batches to provide similar film sensitivity, sensiometric checking of the three dye layers to determine any change in their dye sensitivity, careful exposure, and special processing facilities. Automatic exposure is crucial as a 1/2-stop error in exposure seriously affects color quality. Infra-red photography has been used for assessing production of forage legumes in the field (2), extent of legumes in grass-legume hayfields (3), grasshopper damage, winter survival of alfalfa (11), rangeland productivity (13,15) and crop identification (7).

The launch of the resource satellite series (Landsat) in 1972 created a greater awareness of the spectral response of crops under field conditions. Technologically, it is now possible to obtain regional imagery of crops and to assess conditions of crop growth for fields over 20 acres in size. However, repetitive coverage by satellite once every 18 days (e.g. Landsat), combined with a high frequency of cloud cover seriously interferes with regular use of the imagery.

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*See list of references

Scale and Costs

There is a direct trade-off between observable detail in an image and scale and between scale and cost (12). If information is required on the location of crops which are grown in an area close to a market or a processing plant, a scale of 1:30,000 (1 inch to 0.5 mile) or 1:63,000 (1-inch to 1 mile) may be acceptable (7). If details of evenness of crop growth within a field is the required information then scales near 1:3,600 (1 inch to 0.25 mile) may be required (2,11). Table 1 shows the relative increase in photography costs as the scale changes from 1:63,000 to 1:980 to provide increasing detail within a field.

Current Applications

In addition to using the large format metric cameras (230 mm) for mapping land-use, soils, crops (7), rangelands (13), cover crops (1), ecological features, land resources and environmental studies, the smaller cameras (70 and 35 mm) are useful for local recording of specific features (2,15). These include photographs to record drainage patterns, individual farms, or uneven crop growth. Delineation of poor growth within fields may be useful in illustrating crop loss from poor cultural operations, uneven fertilizer or chemical applications, or damage from spray drift, poor drainage, and uneven soil or moisture conditions. Information on previous cropping and cultural practices is required to assist in analyzing the causes of an uneven crop. Cropping or cultural practices of the previous year will show up. Previous field boundaries are frequently observed. Regardless of whether the observed effects were caused recently or in the past, the image provides excellent delineations of the problem area and the location of any unique features associated with it. In assessing vegetative productivity of an area, careful consideration must be given to the growth stage of the crop to enhance the features of concern.

Future Applications

New developments are underway in the use of airborne video systems for recording crop images on magnetic tape. Present commercial units provide images of individual fields in normal color. The advantage of a video system is that the scene may be viewed immediately upon landing and not several days later.

This is particularly advantageous where a record is required of extensive damage from insects or disease. However, wide coverage of several fields is not possible with current video cameras. Electronic laboratories are now developing a variety of new video cameras. The new systems will have a wider spectral response to include the near infra-red spectrum.

Other new developments in remote sensing which are not yet readily available include the use of solid state electronic camera systems for images in specific narrow spectral bands. Bands will then be selected to provide images of features unique to specific crop features. Some research is being undertaken in Canada in identifying specific spectral response of various crops, growth stages, water stress effects and crop damage.

Research is underway in Canada to determine the amount of various atmospheric constituents which affect growth of crops. These include CO_2, NO_2, NH_3, fluorescence of certain plants, and protein content of the plants. These constituents are detected by their biochemical capability to absorb radiation at very specific wavelengths. By analyzing the amount of radiation relative to normal radiation, the presence of these compounds can be determined.

Application of spectral imagery from satellite-based systems has been studied in the last twelve years for crop acreage and growing conditions (1,5,9,13). These studies, based on Landsat data taken at a spatial resolution of 80 m (1 acre per measurable unit area), show that such imagery can be used for estimating acreage of the main types of crop (cereals, rangelands, oil-seeds, fallow, etc.), and also for evaluating general growing conditions over large areas. As the resolution of the imagery improves from 80 m to 30 m with new satellite systems (e.g. Landsat 5, SPOT etc.) and as the frequency of coverage improves from once every 16 to 18 days to daily coverage, more specific information on the crops and crop development should become available. However, the improvement in the frequency of coverage over the area in the spatial resolution is offset by increases in amount of data generated and in the costs of transmission and processing the data. At present Landsat data may be enlarged to a scale of 1:250,000 (4 miles per inch) and still maintain clear definition of the fields.

Since 1978, studies on developing applications for radar imagery in Canada have been underway on a limited scale (4,8). The microwave system (radar) will provide imagery regardless of cloud conditions. Initial studies indicate that various crops differentially effect the radar image. Research studies are required to develop procedures for applying microwave imagery to agricultural requirements for the launch of a Canadian satellite in 1990.

CONCLUSIONS

Photographic and electronic systems are available for assessing crop types, land-use, cropping practices, crop conditions and crop damage from insects, disease and cultural operations (e.g. chemical sprays, tillage, fertilizer). Whether a 35-mm, 70-mm or

230-mm camera format or a home video system is selected, depends greatly on economics of aircraft use, area of land coverage needed, the resolution needed to identify features, the detail needed of individual plant or field features, availability of systems, control of flight schedules, weather conditions, and demonstrated experience of operators in acquiring the data and interpreting the imagery. Remote sensing is a powerful tool now coming into use for agricultural applications and its use is expected to expand rapidly in the immediate future.

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Table 1. Number of frames required to cover a 10-mile flight line at various scales for two types of cameras.

Scale of image	One inch on image is equivalent on ground to	Camera Altitude 6" lens (AGL ft)	Frames per 10 mile flight		Swath width (miles) with 10% overlap	
			230 mm camera	70 mm camera	230 mm	70 mm
1:63,360	1 mile	31,680	1.0	5	8.1	2.02
1:31,680	0.5 mile	15,800	1.2	10	4.0	1.01
1:15,400	0.25 mile	7,900	2.5	20	2.0	0.51
1:9,600	800 ft.	4,800	8.2	33	1.2	0.31
1:3,920	330 ft.	1,980	20.2	80	0.4	0.12
1:1,960	165 ft.	990	40.2	160	0.2	0.06
1:980	82 ft.	455	82.07	320	0.1	0.03

Table 2. Relative cost to photograph, in color, a 10 mile area at various scales (10% overlap).

Scale	230 mm Camera
1:63,360	1.44 unit cost
1:31,680	5.66 unit cost
1:15,400	23.06 unit cost
1:9,600	59.3 unit cost
1:3,920	355.0 unit cost
1:1,960	1423.0 unit cost

Paper No. VIII-A

FUTURE AGRICULTURAL PRODUCTION

E.J. LeRoux
Assistant Deputy Minister, Research Branch
Agriculture Canada
Ottawa, Ontario
K1A 0C5

ABSTRACT

The present constraints facing agricultural production are examined and the direction agriculture will follow in the future is discussed. The Research Branch of Agriculture Canada will play a role in supplying new cultivars, techniques and equipment. The need for improved pest control is shown to lead to Integrated Crop Management Systems, which will result from continued research and close cooperation between all interested groups. An expanding role for aerial application of biological materials is foreseen.

INTRODUCTION

I welcome the opportunity to speak at this symposium and commend the multidisciplinary approach being taken to an area that is increasingly an integral part of Canadian agriculture. Growers find themselves under economic and environmental pressures, and so they are searching for gains in efficiency and productivity. In order to make these gains, economic and fast ways of applying everything from seed to fertilizer are being sought. Pest control is one of the areas where aviation is growing in importance. Other areas have been discussed at this workshop.

CANADIAN AGRICULTURE IS IMPORTANT TO THE NATION AND THE WORLD

At present, agriculture provides 18% of Canadian jobs and one sixth of Canada's GNP. Approximately 1/2 of agricultural production is exported (9B$), leading to a $4 billion surplus in our balance of payments in 1982. However, there is room and a need to improve these figures. Currently international demand for agricultural commodities is weak. There is no doubt in my mind that if we use this as an excuse to lessen our efforts to increase productivity and relax our research activities then at some future date we will find ourselves unable to meet demand or compete in foreign markets. We cannot live on stockpiled research and technology, especially when others will be advancing the leading edge to suit their needs, not ours. Of course, in addition to continuing our research endeavours, we will be maintaining and increasing our efforts in the two other major areas defined by Agriculture Canada's Agri-Food Strategy - namely marketing and the resource base. These areas work hand-in-hand to outline the course agriculture must take in Canada to give us inexpensive, wholesome food and exports.

CONSTRAINTS AFFECTING PRODUCTION

The Agri-Food Strategy, which summarizes the federal government's position, details a plan for Canadian research and development that will help us meet the producers', marketers', and consumers' demands. There are major constraints influencing growers that must be taken into account by all activities under the Agri-Food Strategy.

Energy

Energy costs are incresing. These are not just the direct costs such as fuel, but also the indirect costs that the grower must shoulder such as nitrogen-containing fertilizers.

Mechanization

The labour/mechanization ratio is difficult to optimize and maintain. Labour intensive operations are becoming increasingly difficult to justify, but the cost of mechanization is in some cases prohibitive for the small grower. This balance, when productivity and cash flow are taken into account, may decide whether an operation continues or not (e.g peaches on the Niagara Peninsula).

Increased Production

The demands for more production and more types of product require increased efficiency of production, more land under cultivation, and a strong program of mission-oriented research.

Marginal Land

The areas of Canada that are now considered marginal for production will have to be brought into agricultural use in the future. This will entail special efforts to classify these marginal lands, and new cultivars and management techniques to exploit them to their fullest. Recent developments in beef production in northern Ontario are an example of what can be achieved.

Pests

Insect pests, weeds, and diseases continue to be major threats to productivity. Unfortunately we will never be able to eradicate them completely, especially when they keep changing to meet our attempts to destroy them or minimize their effects.

This is by no means an exhaustive list of the problems which the growers face but it at least gives an idea of the herculean task they, and we, are trying to deal with.

THE ROLE OF AVIATION

What part can aviation play in the solution to these problems? We are standing at the edge of a major change in the application of technology. The tractor revolutionized agricultural production and efficiency; similarly the airplane holds promise for the future of agriculture.

Seeding

It appears that aerial seeding may not be more economical than ground application for some situations. Application rates are variable and no gain in time may be obtained because the seed must be worked into the ground soon after it is broadcast. Genetic engineering to produce seed that doesn't require working in, may make more aerial seeding feasible. When the terrain is rough, such as for rangeland, aerial seeding may be the only way and its use in these situations is expected to increase. This is one of the ways we will have to exploit marginal lands.

Fertilizer

Aerial application of fertilizer holds promise. Again, it is presently being used over rough terrain and rangeland. Its drawbacks include the present lack of knowledge of the rates required and the optimum dispersal mechanisms to ensure a good job is done. But, every time material is delivered from the air, this means one less pass over the field by a tractor. This helps deal with the problem of soil compaction.

Pesticides

At present the major use of airplanes is in the application of pesticides - some 3M hectares were flown in 1981 and this is rising. It is also here that some of the major problems occur. The chemicals being applied are toxic and this gives rise to two related areas where more work is required - drift and safety.

Drift

Drift from aerial application is usually 10 times and more than that from ground application. There is work being done by the National Research Council, but this is primarily for forestry operations. We are hopeful that with some changes in the meteorological assumptions some of this can be applied in agricultural settings. A factor affecting drift is droplet size and results depend heavily on this. But first, in the agriculture context, we need to assess the relation of droplet size to the efficiency of the pesticide being applied. With this question answered, we can study the mechanisms of producing the uniform droplets, or the spectrum of droplet sizes required, and how to minimize their drift. There are commercially available ground applicators that depend on electrostatic force to deposit the material. This method needs to be tested more extensively. Improved ground sprayers are being developed that not only reduce drift (e.g. to 0.4%) but because of efficient deposition reduce the quantity of chemicals and water needed to achieve effective control. Thus there is a definite competition between aerial and ground applications. If aerial spraying is to expand then it will have to meet this competition by doing a better job.

Of course, the role of atmospheric conditions cannot be downplayed; again much more research must be done in this area.

Safety

I use safety here in two aspects: safety of our ecology, and safety of personnel. Acceptable control of drift both from an ecological and an effectiveness point of view depend on accurate location of the aircraft while it is delivering its payload. Cheap, reliable and accurate instrumentation must be developed in order to reach this goal. The development of pesticides more benign to humans, such as the new biologicals, and the testing and certification of existing pesticides for aerial use, must continue.

The spin-off of course is added safety for ground personnel by reducing the need for flagmen or others to be near the spray site. Biological controls, which often depend on widespread dispersal, for example sterile noles, seem ideally suited to aerial application.

"Idle?" Speculation

The ultralight aircraft is being promoted for aerial applications. They are easy to maintain, easy to control, and cheap. They offer the advantage of slow speed and low altitude but suffer from small payloads and a restricted set of weather conditions during which they are usable. With work they may become a delivery vehicle in the future.

It is apparent from this discussion and the preceeding papers that although research is being done, there remain many areas for research to make significant breakthroughs. I would like, however, to focus some attention on the problem of pest management and how this area will develop.

PEST MANAGEMENT

More than 60 professionals in the Research Branch are investigating - and have several notable commercial successes with - Integrated Pest Management Systems, particularly in fruit and vegetable crops. We have a wide arsenal of insecticides available and we are responding through research to concerns expressed about their use. Studies are ongoing in crop placement, rotation and management to minimize pest and weed effects. Naturally occurring organisms such as bacteria, viruses, and insects that hold promise as biological and microbial control agents are being investigated. What does the future hold? We are going to have to take our present efforts and extend and expand them - but most importantly, we must coordinate them. Not one of the existing techniques is the solution to the problem, primarily because the overall problem is a multiplicity of constraints, aims, costs, and decision criteria.

TIMELINESS - A PROBLEM AND ITS SOLUTION

Growers will always need quick solutions to unforecast pest problems. For instance the Orange Blossom Wheat Midge that has just appeared in the Nipawin-Arborfield area concerns us. This pest has been reported in small numbers for years, but except for a small outbreak in the mid-fifties near Winnipeg, it has been largely confined to the coasts. However last year some 250,000 acres were infected and the resulting crop loss is estimated at $30M. The cocoons are in the ground and we are expecting new outbreaks this year. While we recommend that canola, flax, barley or other crops be grown in the area, we must continue to provide support to wheat growers. Agriculture Canada has been asked by Saskatchewan Agriculture to consider temporary emergency registration of some insecticides for control of this insect. However, since any insecticide will be aimed at killing the adults after emergence but before egg-laying, timing of spray is critical. There will be monitoring of suspected areas and emergence information will be provided. The short time for effective treatment, plus the fact that the wheat will be headed, require that aerial application be used. Such situations emphasize that we must continue to foster the development and testing of new chemicals; we must monitor the on-going efficacy of existing pesticides and relate this to acquired resistance by the pests and its mechanism of action; we must not lose sight of the environmental impact of pesticides and we must develop delivery methods. Each of these areas entails research. In the present context, for instance aerial spraying of pesticides is a little understood technique - What is the best droplet size; How can can optimum concentration be obtained where needed without detrimental levels in on- or off-target areas; How is drift to be reduced or eliminated; Are some chemicals inherently unusable from the air; and so on.

ECONOMIC ASPECTS

In addition the economics of aerial application require investigation. For the typical user, the fixed overheads of aerial spraying may make it expensive when compared to ground methods. However the payback in terms of speed of response to an insect threat may outweigh the cost disavantages. As more technology, and this includes both hardware and materials, is developed and transferred to the private sector, it is expected that economies of scale will expand aerial applications. This expansion will be both in total area covered and in a broadened range of materials applied from the air.

INTEGRATED CROP MANAGEMENT SYSTEMS

Integrated Pest Management Systems offer hope in the control of harmful insects, but their drawbacks include a requirement for continuous monitoring and a slow response to sudden unforecast jumps in pest populations. Aerial and ground application of chemicals give an immediate return on investment but possibly place the environment at risk. All these systems are necessary and will be in place increasingly in the future as integral parts of a total crop management scheme.

Many groups are working on parts of the puzzle. The Research Branch of Agriculture Canada is conducting research on all the biological aspects including, recently, a new focus on engineering research on aerial application. The National Research Council has a program on aerial spraying that has focused on forestry. The provincial governements are heavily committed to extension services and the provision of up-to-date advice to growers. Research is being carried out in many universities. There are organizations such as ACAFA that are intimately involved in research, development, and advice. And, of course, there is a wealth of knowledge and experience in the commercial groups and the growers that we should not ignore.

The picture I foresee, then, is one in which close liaison between the research and delivery programs of the federal and provincial governments and the universities, and input from the growers will lead us to Integrated Crop Management Systems. These are systems where informed choices can be made about what to grow, where to grow it, and what to treat it with to most economically minimize the harmful effects of pests while maintaining and increasing production and production efficiency. We are working on many aspects of the problem now. What is required to achieve the long-term goal is close cooperation between the groups involved and a coordination of programs. Such meetings as this one form an important part of this cooperation and coordination and must continue if we are to produce and agriculture system that can withstand the buffets of nature and respond to the needs that will come in the future. Agricultural production will expand, I am confident, as will the demand for our products. We are aiming all our efforts at this, in research, in resource base increases, and in market development. This expansion will bring with it an increased requirement for the timely and economical application of seed, pesticides, fertilizers, and I can only foresee that the use of aircraft on the farm must grow.

Paper No. VIII-B

POTENTIAL FOR FUTURE SPRAYING BY AIRCRAFT IN CANADA

K. Price
Plant Industry Division
Alberta Agriculture
7000 - 113th Street
Edmonton, Alberta T6H 5T6

The future for Agricultural Aviation in western Canada cannot be accurately predicted without knowing what action governments will take. This greatest unknown will artificially impose on the normal forces for and against the expansion of agricultural aviation and (in my opinion) will be the dominant force.

Primarily I am speaking of the regulatory stance toward registration of pesticides for aerial application. It is a fact that the aircraft receives special (discriminatory) treatment compared to other application devices. This relates mainly to the aircraft's known high drift potential. However other machines such as spray coupes and floaters are known to have some undesirable characteristics and receive no special treatment on the pesticide label. The aircraft also receives discriminatory treatment with respect to fuel tax when compared to competing methods of pesticide application. I will return to this topic later.

In considering the future potential for agriculture aircraft I first thought of fertilizer application and seeding operations. There are some people doing both of these things with aircraft, but the potential is limited. The aircraft has few inherent advantages over ground application for these operations and has several disadvantages - mainly high cost, but there are others. The aircraft's mobility around areas cut up by urbanization presents an advantage compared with the difficulty of moving farm machines along heavy traffic routes and limited access roads. This advantage is offset by noise complaints and heavy air traffic in the same areas. In any event the farmer must do a tillage operation to cover the seed or fertilizer and in so doing usually chooses ground application where the application and tillage may be combined in the same operation. For this reason I can see no large demand developing for seeding or fertilizing except in forestry operations, which is a different story but outside of the scope of my paper.

The major potential for aircraft usage is in those areas where there is an inherent advantage or where aerial spraying is the only method of application. To the traditional operations of weed and insect control may be added recent developments in crop desiccation as a harvest aid and disease control on a large scale in field crops. Both of the latter are in their infancy but promise a more reliable and perhaps larger market than does insect control, which is characterized by large variations from year to year.

I have tried to look at the future by carrying out a simple force field analysis. I considered the forces that would act to cause a large increase in aerial spraying and those that would restrain such a development:

Driving Forces	Restraining Forces
Speed of application	Drift
Ability to operate over mature crops	Cost (high)
	Newest products not registered by our control agencies
High mobility	Bad reputation (sloppy or daredevil)
Ability to operate over soft or rough terrain	Lack of information and test results

Some of the forces are weak and may be disregarded. We will examine the more powerful forces in detail.

The ability to operate in a mature crop without damaging it and the capability to operate over soft wet fields is so compelling an advantage that often aerial application is the only method available. In these cases the choice is, "spray by air or don't spray at all". The same is true of most forestry applications.

Balancing these powerful reasons to use aerial application are several equally powerful restraining forces. It is generally accepted that the best way to achieve a desired change is to weaken the restraining forces rather than to strengthen the driving forces. Fortunately there is only one inherent restraining force, the others are all artificial. Let's examine them one by one.

(a) Drift - the higher drift associated with air spraying cannot be denied. Inherently it will always be greater than with ground application. Any new drift control method that may be developed would likely also be applied to ground equipment so the gap would remain. However, there is potential to reduce drift to the point where it is no longer a major concern by either ground or aerial application. This would eliminate the most powerful force which is restraining aerial application. The solution would require a technical breakthrough. That implies research on a pretty large scale.

(b) Reputation - I do not expect that my comments on the next item will win me a lot of friends in the aerial applicators ranks. I am their friend and supporter but facts must be faced. Deserved or not, aerial applicators have achieved a bad reputation amongst many farmers and agrologists. Every year stories circulate which add to or aggravate the problem. For example:

  (i) Damage to gardens or shelterbelts.
  (ii) Spraying of bees or fish ponds.
  (iii) Drift damage to neighbouring susceptible crops.

This issue must be addressed and dealt with. While Legislation now exists in most provinces to licence applicators and enforce a minimum standard, the key word is minimum standard. The industry itself should be considering a code aimed at achieving a high level of professional standards. High standards must be voluntary. They must be accepted by the industry - they cannot be legislated. All legislation can achieve in setting standards is to bring the worst operators up to a minimal acceptable level, you cannot legislate or enforce excellence. However, the industry can act in concert with regulatory authorities to remove questionable operators. In this respect the regulatory people must be looked upon as long term allies of the industry rather than as enemies of the operator. This is one restraining factor to increased aerial applications which may be reduced by the actions of the air sprayers themselves. Every pilot must be enlisted to do their part.

The remaining two restraints to aerial application are beyond the control of the aviation community. They must be dealt with by the chemical manufacturers and the federal government.

It is imperative that chemical manufacturers realize the potential of a strong Agriculture Aviation Industry and the role that this industry will play in the application of new growth regulator and disease control compounds. The major pesticide manufacturers must be pressed to apply for aerial registration of their newest pesticides. If this is not done, the aerial applicators will wither for lack of products that they can apply (legally). The pesticide manufacturer must be convinced to invest the extra capital to achieve aerial registration even on products where the expected benefit may do no more than achieve a break even position. Perhaps they should even consider a loss position as a long term investment to be repaid in sales of a future product which may be wholly dependent on air application, and for which a viable aerial applicator will be a prerequisite for the product to be successful.

The pesticide manufacturer must be supported in this effort by an awareness on the part of Agriculture Canada that aerial registration cannot be viewed solely on a product by product basis. The industry must be supported with access to as many products as possible. The aerial applicator cannot be expected to starve between emergencies and then arise to deal with the occasional disastrous insect outbreak or a weed problem which is compounded by excessive rainfall and soft muddy fields. Whenever there is opposition to a registration both the manufacturer and the regulator seem too prepared to sacrifice aerial application from the label as a concession to opponents in return for approval of ground application.

Registration, recommendations and ultimately adoption of aircraft application of pesticides is also being hampered by the total absence within Agriculture Canada Research of a proper facility to do research on pesticides applied by air. We are not likely to get a Research station equipped with a runway and spray plane, but some protocols could be worked out to standardize testing of chemicals applied by air and arrangements made to have commercial applicators spray plots to the researchers specifications. Some specific scientific data on the results a farmer can expect from pesticides applied by air should remove this last major barrier.

Returning to an earlier point, I wish to expand on what I called discriminatory regulations against aircraft. As I mentioned there is no other type of sprayer which is so subject to regulations:

(a) Aircraft are singled out on the label as requiring specific approval.

(b) Aircraft are subject to fuel tax whereas ground equipment is not.

(c) The operator is subject to the air regulations in addition to pesticide regulations but there is no comparable set of regulations with which ground operators must comply.

I would like to summarize the changes which I feel must occur before aerial application can achieve its true potential for the operators and for Canadian farmers.

1. Improve techniques for drift control.
2. Remove discrimination against air application on chemical labels.
3. Develop a research capability and test data for aerially applied pesticides.
4. Improve the standards and actively work to change the image.
5. Remove the tax on avgas used in agricultural operations.

If these restraints can be removed or reduced, aerial application has the greatest potential for increase in the operations where it is currently being used, weed and insect control.

The single greatest acreage potential that exists right now is probably herbicide application in the black and grey wooded soil zones. The parkland areas of western Canada. In these areas the weed problem is much greater than it is in the plains region, rainfall is greater so access onto fields is more of a problem. Yields are higher so the extra cost of aerial application should be less of a factor. Traditionally this vast potential has not been fully developed because of:

(a) Small fields and large amounts of bush which impede the actual flying operations.

(b) Poor weather for flying - more days of rain and low cloud compared to the prairies.

(c) The major factor has probably been the diversity of crops which increases the chances of damage by herbicide drift.

The small fields have been changing as bush is cleared and sloughs drained. The field size now compares with the south, the cloudy, rainy days are offset by more days with lower windspeed and the drift problem can be dealt with by improved equipment, spray additives and better sprayer adjustment.

Crop desiccation is another potential which can be developed. The whole area is so new that it needs to be sold to farmers who may not yet be aware of its advantages. Crop desiccation involves a different concept of harvesting. It is an alternative to swathing. The desiccant speeds ripening and kills green weeds in the standing crop. The crop is then straight combined rather than being swathed, left to dry and harvested using a pick-up attachment on the combine.

The traditional advantage of earlier harvest is maintained, the green weeds are killed and allowed to dry prior to combining as is the case with swathing but several advantages are achieved:

(a) Replacement of the swathing with a higher speed operation.
(b) Savings in the capital cost of the swather.
(c) Standing crops dry much quicker than swathed crops, are less susceptible to duck damage or damage from the wind rolling the swaths.
(d) The standing crop is nearly invulnerable to the rotting or sprouting loss that occurs when swaths are rained on for a prolonged period.

The disadvantages are:

(a) vulnerability to hail damage for a longer time
(b) the danger of the crop lodging.

Both of these possibilities are reduced by the use of growth regulators which we will discuss next.

The application of plant growth regulators to improve yield, strengthen straw and otherwise enhance crops (earlier maturity) is a field of intense development by chemical companies at the present time. Also under intense development are foliar applied chemicals for disease control. Leaf and head diseases of cereals are on the increase in Canada. They may be expected to increase even more if farmers intensify efforts to achieve maximum yields.

The application of both disease control fungicides and plant growth regulators is common in Europe already. The reason is that higher land and grain prices have provided the incentive to go for maximum yields. As we move in this direction in Canada both of these practices may be expected to grow in popularity.

The significance to aerial application is that both the plant growth regulators and the fungicides are applied at advanced growth stages where trampling losses from ground application are high. The only alternative to aerial application is the practice of tram lining (roadways are left in fields for the equipment to travel).

Fungicides and growth regulators are applied in midseason and have the potential to fill the gap between spring weed spraying and fall desiccation to make aerial application a full season operation. I need not elaborate on the advantage to the operator - more stable employment for pilots, better utilization of aircraft, smaller radius of operation from base, higher income to the operator and lower per acre application cost to the farmer. These could act synergistically to push the use of aerial application even higher.

If even some of the forces restraining aerial application can be reduced and if aerial applicators will work together to improve the image of agricultural aviation a doubling of acreage over the next five years would be a modest goal.

Paper No. VIII-C

TRAINING OF PILOTS

Ray Hrabats
Director, Aerial Application Program
Lakeland College
Vermilion, Alberta
TOB 4M0

ABSTRACT

The need for formal as opposed to on-the-job training of agricultural pilots is discussed. A training program is outlined that could be used to train future pilots for agricultural operations.

INTRODUCTION

An individual's performance and success in any vocation is directly proportional to the quality of training received. This is the justification for our entire educational system.

As a profession, aerial application is very young. There are still many people living today who were here when the first aerial application was done. Many others have never seen an agricultural aircraft work. Fortunately, agricultural aviation did not have to develop unilaterally but was able to take advantage of the explosive growth in aviation and technology.

Unfortunately, training in Canada has not kept pace, there is no comprehensive program for training agricultural pilots. The industry up to now has relied on a combination of self teaching, informal on-the-job instruction and instruction from the occasional operator who does it simply to take up some of the slack in the off-season. When one considers the sophistication of modern airplanes, chemicals and application systems it becomes obvious that these methods of training must be improved.

There are some who would defend the present system, saying that it separates the committed pilot from the uncommitted, the strong from the weak, the lazy from the ambitious. They feel that the agricultural pilot must pay his dues, that he must be willing to work long hours at related tasks to prove his worth before he gets a chance to fly. Going to school makes it too easy to get into the profession, they feel. Obviously this approach may have great emotional appeal, particularly to someone who got into the industry in just this fashion.

However, there is another aspect to this situation. Currently, insurance companies refuse to insure anyone with less than 25 hours agricultural flight time. Between the 25 hour and 99 hour mark the aircraft owner pays an additional 33% premium. The cost of insurance can become prohibitive, often exceeding the pilot's wages for the season. The new pilot who does not have connections or sponsorship is thus faced with a number of alternatives if he wants to get into the business.

1. He can buy (finance) a used aircraft and fly it uninsured, picking up work as best he can until he gains more experience and enough hours to qualify for a more reasonable insurance rate. Is this a good learning situation?
2. He can work for an operator who cannot or does not want experienced pilots. Such an operator is generally known for high turnover, poor equipment and poor results. Is this a good learning situation?
3. He can work for a reputable operator as a loader, mixer or flagger. In this situation he may do the occasional ferry flight and gradually work his way into the business. Although sometimes drawn out, this, of the three methods, generally produces the best results. However, top operators are characterized by low turnover. Also, the aspiring ag pilot often works so hard to please that he becomes too valuable in a support role and becomes locked into the wrong job. What kind

of work habits does the new pilot pick up in these situations? How many potentially good pilots quit in frustration?

A PROPOSED SOLUTION AND ITS ADVANTAGES

Would it not be a far better alternative to have a training program that is so comprehensive, so thorough, so demanding that it will not only produce a top quality ag pilot but will also eliminate the pilots who are not committed to this type of profession? In spite of the criticism that schools often receive for removing training from reality, a program that does those three things is not only possible, it is a necessity.

What are the benefits?

1. The new pilot receives training that not only makes him a better and more efficient flier but which also exposes him to the latest technology in the industry.
2. It is very possible that a graduate of a program will be subject to a lower insurance premium. This makes him more employable.
3. The operator will be hiring a pilot who does not have to be retrained. The new pilot would merely adjust to the operator's particular methods, since he already has good basic skills.
4. The operator will pay a lower insurance premium on the new pilot.
5. Even though the operator may be using only time-proven methods of application, he will have access, through the new pilot, to information about new technology. This can only improve his efficiency and effectiveness.
6. The Environmental Protection Agency in the U.S. estimates that it can cost them up to $80,000 to process a complaint relating to spray drift from agricultural aircraft. It is reasonable to assume that a well trained pilot, aware of the consequences of improper application and having the skill to do it right would be saving the public money. A public education program that

would be a necessary accompaniment to a training program would do likewise, especially when one considers the emotional nature of public reaction to agricultural chemicals. Better training results in better work which results in fewer complaints which leads to fewer people harassing our provincial environmental people and demanding controls, regulations, investigation and enforcement. The cost of a good training program becomes an investment, not an expense.

7. There are many programs involving pesticide research and registration that are being held up because of the unavailability of a location and aircraft. A proper training centre could form a focus for such work.
8. A computerized spray analysis system that tests the efficiency of an aircraft could be part of the program. This equipment would assist the provincial aerial applicators associations to upgrade their members' aircraft and enable them to proceed much more rapidly towards their goal of self regulation. Again, this would greatly reduce if not eliminate the need for government regulation and the attendant legislation, enforcement and expense. In addition, a regular series of seminars would help upgrade applicators' knowledge of the latest developments in the industry. These would benefit commercial operators and flying farmers alike.
9. The Training center could become a testing center for aerial applicators wanting their "E" license. This would reduce the workload on the Environment department.
10. There is every reason to believe that such a training program could lead to the College becoming a center for research into aerial application and for the dissemination of knowledge in this field.

Lakeland College is proposing an agricultural pilot training program that will improve the quality of agricultural aviation in Alberta and Western Canada.

The objective would be to produce superior agricultral pilots, and establish a broad program of education, leadership and research in the field of agricultural aviation.

THE IDEAL APPROACH

From an educators viewpoint the following is an ideal approach to training. The ground school should not be taught by the traditional classroom method but through a combination of video tapes and computer assisted programmed learning. Regular examinations and instructor monitoring and aid should be part of the program. There are a number of definite advantages to this teaching approach:

1. The aircraft can fly throughout the day, instead of being shut down during good flying weather so that students can attend a common class. A student would put in his flying time and then work on his ground school on an individual basis.
2. There is no need to find outside instructors to do parts of the ground school. Instructional costs are greatly reduced.
3. Since all of the ground school is under the control of one person, it becomes easier to maintain a consistently high level of training. Further, it is much easier to make changes to the program and keep it current.

GROUND SCHOOL - COURSE OUTLINE

1. Chemistry of Pesticides - 5 hours
   Types and composition of chemicals
   Classification by characteristics and purpose
   Formulation, compatability
   Volatility, acids and bases
   Colloids and their properties
   Surface active agents
   Solubility and leaching
   Absorption and decomposition
   Drift control agents and spray additives

2. Insect and Insecticides - 10 hours

Insect pests of field crops, fruits, vegetables and forests
Identification and economics of control
Beneficial insects and pollinators
Selection of products and biological effectiveness
Area and target dosage rates
Persistence and interaction
Mode of action of insecticides
Timing of application, limitations, resistance, residues
Life cycle, insect tables
Insecticide types and uses
Public relations with beekeepers
Bio concentration - bio degradability
Botanical pesticides, synthetic pesticides
Integrated control programs
Over winter storage and handling of insecticides
Label information and interpretation
Tank mixes and problems
Application problem calculations
Specimen identification

3. Weeds and Herbicides - 10 hours

Introduction to weed control
Identification of crops and stages of growth
Chemical methods of weed control
Selection of products and biological effectiveness
Area and target dosage rates
Persistence and decay
Mode of action of herbicides
Dosage and formulation
Timing of application, limitations, residues
Pre-plant, pre-emergence, post-emergence treatment
Annual crops vs. perennial crops

Forage crops, cereal crops, specialty crops
Efficacy, compatibility and tank mixing
Selectivity and spray additives
Contact vs. translocated herbicides
Corrosion and abrasion
Brush control and dormant sprays
Aquatic fauna and herbicides
Over winter storage and handling of herbicides
Label information and interpretation
Application problem calculations
Specimen identification

4. Botany and Environmental Considerations - 5 hours

Classification of plant kingdom
Identification of mature weed plants
Identification of shrubs and trees
Identification of seedling weeds and crops
Identification of crop and forest diseases
Timing of applications, limitations, residues
Bio contamination, non target species
Bio magnification and residues
Balance of nature
Biological control
Fungicide types and uses
Pesticide effects on birds, fish and wildlife

5. Soils and Fertilizers - 5 hours

Soil types and classification
Base exchange and soil fertility
Fertilizer types and uses
Soil pesticides and persistance in soil
Aerodynamic properties of fertilizers and seeds
Mixtures and segregation

Rates of application and deposition density
Application problem calculations

6. Safety and First Aid - 5 hours
   - Poison control centres
   - Pesticide modes of action
   - Shock signs and symptoms
   - Artificial respiration
   - Treatment of burns
   - Minor and severe external bleeding
   - First aid - major contamination
   - First aid - minor contamination
   - First aid to poison victims
   - First aid kit for applicators
   - Local hospital arrangements
   - Safe practices, clothing, respirators
   - Symptoms and treatment of toxicity
   - Toxicity of chemicals and formulations
   - Toxicity to humans, animals, wildlife and fish
   - Pilot fatigue
   - Respirator - canister characteristics
   - Firefighters jumpsuits, boots, gloves
   - Communications, earphones, microphones
   - Crash helmets, visors, air filtration

7. Regulations and Legal Considerations - 5 hours
   - Pesticide development and regulations
   - Pesticide legislation and recommendations
   - Storage, handling, labelling, and disposal of containers
   - Drift hazard and responsibility to the public
   - Transportation of chemicals
   - Food and Drug Act
   - Pest Control Products Act

Alberta Agricultural Chemicals Act
Pesticide labels
Contamination and confiscation
Environmental protection agencies
Pesticide dealer and classes of applicators

8. Business - 5 hours

Principles of accounting
Costing of operations and management
Contracts, tenders and records
Forms of business ownership
Approaching lending institutions
Taxation
Pre-planning and organization
Job - field records, pre and post application
Computer based accounting
Starting a business
Obtaining a charter
Employer obligations
Purchase, licensing and import of equipment

9. Insurance and Regulations - 5 hours

D.O.T. regulations
Aircraft maintenance and certification
Accident reports
Personal and commercial insurance
Public liability insurance

10. Mechanical Systems - 10 hours

Sprayer system and components
Aerial calibration charts
Granular application - spreader types
Calibration - liquid and dry - effective swath width and uniformity

Volume spray - droplet size, drift
Location of nozzles and atomizers
Pump performance and repair
Hopper and spreaders
Assembly - disassembly - cleaning, decontamination
Emergency dump systems
Decontamination of equipment and work areas
Principles of deposit and uniformity, overlap
Typical deposit density graphs
Particle size, uniformity coverage, application rate
Measurement of particle size and distribution patterns
Displacement techniques and estimation
Drift and particle size
Procedures for drift prevention
Mixing equipment and loading systems
Corrosion and its prevention

11. Maintenance - 15 hours

Practical assignments in maintenance of an aircraft and its application systems
Installation and rigging of application systems
Supervision of contracted maintenance

12. Debriefing Sessions - 20 hours

These question and answer sessions should be scheduled on a daily basis to clear up any problems that may have developed during the day. Practical tips and new equipment should be discussed.

Total ground school - 100 hours

COURSE OUTLINE - FLYING

The purpose of this course is to make a pilot safe, competent and employable. By using the Cessna 185 and 188, the student gets an immediate exposure to a complex aircraft. The Cessna 185 gives the instructor a convenient teaching platform and eliminates the inconvenience and hazard of peering over the student's shoulder. The student flys in the right seat so that his controls are in the same locations in the agricultural aircraft.

The makeup of this course is such that the student is placed in a realistic and challenging environment. He has plenty of opportunity to safely explore the operating characteristics of the 185 in a dual situation. The 185 with spray gear is very similar in operating characteristics to the 188. Consequently, the transition to the 188 will be comfortable and safe. All solo work will be supervised, graded and discussed.

The problem areas in aerial application are take offs, landings and turns. This course is specifically designed to make the student familiar with all the various situations he could encounter in these areas and to make him competent in anticipating, handling and preventing any problems.

The flight instruction is based on 2 hours flying per day per student in a one month course. Since it takes only twenty days to complete the required 40 hours, 10 days are left to offset bad weather, maintenance or some other unforeseen problems that may delay training.

Section I - 5 hours dual - Cessna 185
1 hour introduction
4 hours circuits

Concepts taught include altitude control, proper use of controls, illusion of drift at low altitude, proper landing procedure for a taildragger, 180° turns, co-ordinated turns.

Section II - 2 hours dual - Cessna 185 - simulated 40 × 2000 ft airstrip

2 hours dual circuits: downwind take off and landing

The concept introduced in Section I will be carried over to the downwind environment. The procedure turn at constant altitude will be introduced.

Section III - 4 hours - Cessna 185

2 hours dual 100 ft. circuits: landing downwind and into wind without an airspeed indicator

Skills developed in Section I and II will be improved upon with an emphasis on flying by feel.

1 hour dual - seeding altitude - 100 ft.

The procedure turn will be further developed to include the proper altitude gain. Flagging will be introduced.

1 hour solo - seeding altitude.

Proper flagging and flying for granular materials will be further developed.

Section IV - 4 hours - Cessna 185

1 hour demonstration by instructor

Proper clearance of trees, obstacle avoidance in fields, flying over and under power lines, use of a smoker.

2 hours dual - spraying altitude - 10 ft.

Proper procedure for low level flying will be practised using flaggers. Emphasis on wind and field checks and use of a smoker.

1 hour solo - spraying - as above.

Section V - 7 hours - Cessna 185

2 hours dual - special situations

Dumping loads, aborting take offs, partial dumping on short strips, effect of heat and altitude, landing with a load.

3 hours dual - off airport.

Operations from narrow strips and roads will be introduced and practised in downwind, into wind and crosswind situations.

Aircraft will be loaded.

1 hour dual - spraying - manual and auto flagging

1 hour solo - spraying - as above

Section VI - 5 hours solo - Cessna 188

3 hours circuits.

This section will include downwind and upwind takeoffs simulating a narrow strip and will include effects of heat and altitude. Half loads will be carried in the third hour.

2 hours circuits

As above, but with loaded aircraft. Full and partial dumping will be practised as will dumping loads on a target.

Section VII - 6 hours solo - Cessna 188

2 hours seeding - manual flagging,

2 hours spraying - manual flagging,

2 hours spraying - automatic flagging.

Section VIII - 7 hours - Cessna 188

7 hours spraying - farm strips - precision flying will be emphasized.

	HOURS	
Training time	Dual	Solo
Cessna 185	19	3
Cessna 188	—	18
	19	21
	40 hours total	

Paper No. IX-A

PRESENT CANADIAN R&D ACTIVITIES

Peter W. Voisey
Engineering & Statistical Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario
K1A 0C6

ABSTRACT

The Research Branch of Agriculture Canada, provincial governments, universities and industry are involved in agricultural research across Canada. The focus is on basic and applied research in the biology, agronomy and management of crop production. This ranges from breeding new varieties with resistance to disease and pests, the chemistry of insect and weed control to the development of integrated crop production systems. From time to time, the agencies involved have conducted short term projects on aerial applications including spraying, seeding and fertilizer application. However, to date a continuing program of research on aerial applications has not been established.

The National Research Council conducts an aerial spray research program that is focussed on forestry applications. While some of this work may benefit agriculture, the technologies for agriculture and forestry are in principle, different. For example the flying height, area covered, requirements for precision of application, etc. are quite different.

Thus the present situation is that the biological aspects are well covered but little if any work is addressing the aerodynamic/physics studies that are needed. In principle then,

innovations from the biological viewpoint are ongoing but these are not being matched by innovations relating to agricultural aircraft operations in Canada.

What is required is an integrated approach including biological, agronomic, physics and aerodynamic research that can be coordinated to optimize crop management systems involving aircraft use. Currently the missing links are aerodynamic research and a multidisciplinary approach to optimization.

INTRODUCTION

In examining R&D activities supporting agriculture, it is inappropriate to separate out a specific issue such as aerial applications. All agricultural research must be based on the multidisciplinary approach needed to improve production efficiency. Aerial operations is one element in a continuum ranging from biological research on soils, plants, pests and environment to physics and aerodynamics research. Such a continuum is needed to ensure that the aircraft can be fitted into crop management systems efficiently. The spectrum of papers from this Symposium is indicative of the complex team approach that is required.

The picture in Canadian agricultural research is that we have a strong national research effort on the biological side but that minimal continuing effort is deployed on the physics-aerodynamics side.

BIOLOGICAL RESEARCH

A picture of the investment in biological-agronomic research can be gained by recognizing that the Research Branch of Agriculture Canada performs about 50% of this R&D in Canada. The other performers are the universities, provincial governments and industry, with extensive collaboration among the performers. Data for the federal research effort is easy to access, double the following numbers to obtain an estimate of the national effort.

The federal research program involves 3600 people, including 900 professional scientists, working at 50 research establishments across Canada with a total budget of $240 million. About one-third (1200 people and $62 million) are engaged in research on crop production (e.g. plant breeding). Research on crop protection (i.e. pests, weeds, etc.) involves 255 people and $13 million supported by 110 people and $5 million directed to biosystematics (i.e. basic taxonomy and identification of plants and insects). Work on soils and meteorology involves some 270 people and $12 million.

The Research Branch of Agriculture Canada has set up short term projects involving aircraft in spray operations primarily in the Prairie region and in the 1970's on seeding in the Prairies and Quebec. However such activities generally used commercial operators and thus did not involve aircraft fully instrumented for controlled experiments. Available funding appears to limit the amount of experimentation possible. Current examples are: the study of crop canopy penetration at Lethbridge, the use of helicopters to break up inversion layers for protecting crops from frost in Ontario, and the precision application of pesticides on small areas (e.g. around pylons).

There has been considerable effort on crop information systems and remote sensing methods which have been discussed in a previous paper (A.R. Mack). This research has resulted in the development of a commercial service. Agriculture Canada's remote sensing work is in collaboration with the Canada Centre on Remote Sensing of Environment Canada and thus has links to NASA and satellite data, etc. Currently it is being proposed to develop a Canadian crop information centre to take up the developments and provide the information. Prospects in this area then are promising.

Health and Welfare Canada has initiated research on farmer and operator health and safety associated with crop spraying.

AERIAL APPLICATIONS RESEARCH

About a year ago a survey of all establishments involved in research on aircraft operations in agriculture and forestry (Appendix 1) was conducted. This showed that there was little effort focussed on agriculture. The work was primarily done by organizations supported by forestry and focussed on forest applications supporting the major provincial programs on controlling the spruce budworm.

Thus overall in terms of research effort, much of the required research effort and the facilities are in place on agricultural problems with the exception of work on the technology of the aircraft itself and the means to coordinate this research (physics and aerodynamics) with agronomic research. If one examines the Canadian situation, this does not appear logical.

AERIAL APPLICATIONS IN FORESTRY AND AGRICULTURE

In Canadian agricultural production, 120 herbicides, valued at approximately $320 million are used annually to control 35 economically important species of weeds. Similarly, 125 insecticides valued at $63 million are used to control 100 economically important species of insects. This maintains effective production of quality crops on some 69 million hectares.

In contrast, forestry operations involve the use of 7 chemicals valued at $700,000 to control some 20 weed and brush species and 14 chemicals valued at $11,000,000 to control 40 insects on an annual basis. Aerial spraying of an average of 3 million hectares annually for insect control and about 100 thousand hectares for brush control is involved in forest management programs. The principal activity is the use of one chemical to control the spruce budworm.

Agriculture overshadows forestry in terms of diversity of chemical use in pest control. The dollar value of pesticide use in forestry is about 3% that in agriculture.

Over the past decade, the use of aerial spray applications in agriculture has increased dramatically. In the West, some 1.5 million hectares of grain crops are sprayed with aircraft. In the East, 200,000 hectares of various crops are sprayed, some of which are treated up to twelve times (e.g. potatoes). The area flown in Canada thus totals about 3 million hectares. While only a small percentage of agricultural crops are sprayed by aircraft, the majority of forests are sprayed aerially. However, the total area of agricultural crops sprayed by aircraft is fast exceeding that sprayed in forests.

The dramatic increase of aircraft use in agriculture over the past two decades is expected to continue. There is still an additional 60 million hectares of land that can be brought into production that would further increase the need for aerial operations.

The information gained through R&D on forest work is not necessarily applicable to agriculture because the technical requirements are different. Forests are sprayed at flying heights of up to 150 m (depending on stand height) whereas in agriculture it is done almost at ground level. Thus the interaction between the environment, the spray generated on the aircraft booms and the airflow around and from the aircraft, the crop canopy and ground are quite different. There are different requirements for precision of spraying (guidance) since agricultural swath widths are narrower and the areas sprayed are smaller than those in forestry. Drift in agricultural operations may be much more critical in terms of damaging adjacent crops than in forestry applications.

R&D REQUIREMENTS

Required is an integrated program covering physics and aerodynamic research on droplet generation and movement and aerial spraying together with field experiments fully supported by biological and agronomic expertise to study the efficacy of aerial applications. This points to the need for a closely coordinated program between AC and NRC built on the existing strengths. The objective would be to improve aerial spray methods, and their efficacy, reduce drift and thus environmental degradation impacts, and develop more information to permit the formulation of better guidelines and to properly support regulations. The outcome would be safer aerial spray methods to achieve better economic control of agricultural pests.

An important consideration is that the most likely source of significant innovations and improvements lies in basic physics and aerodynamics work on droplet generation and droplet interaction with the airflow around the aircraft. This has already been demonstrated in forestry.

In the current period of constraints we should focus on building on existing strengths. Agriculture Canada has taken the first step in this direction by hiring an aerial spray engineer to interface between biological and physical technology . Ideally we should:

a) Expand the NRC program to fully cover both agricultural and forestry applications of aviation, spraying-seeding-fertilizing and remote sensing, including fully instrumented aircraft of the type used for agricultural applications to capitalize on the excellent expertise base at the flight operations centre of the National Aeronautical Establishment.

b) Organize the Agriculture Canada program to interface between basic physical-aerodynamic and biological R&D programs, namely engineering and the field trials on the efficacy of aviation applications. The research farms already exist and the biological researchers are in place. We just need to plug in controlled experiments with instrumented aircraft.

c) Develop the financial means to support other R&D performers through contracts to integrate and coordinate R&D inputs from the private sector and universities.

POTENTIAL BENEFITS OF COORDINATED R&D

a) Potential for fundamental breakthroughs originating in basic physics R&D to complement the advances being made in biological technology.
b) Improved NRC-AC collaboration, support of other performers and technology transfer to agriculture.
c) Adequate support of AC regulatory functions.
d) Better recommendations to farmers and applicators.
e) Better application, monitoring and prediction techniques.
f) Reduced costs of crop production.
g) Reduced environmental impacts.

APPENDIX 1

ESTABLISHMENTS: RESOURCES AND RESEARCH ON AERIAL SPRAYING (1982)

Maritime Forestry Research Centre
Canadian Forestry Service
P.O. Box 4000
Fredericton, N.B. E3B 5P7
Tel: (506) 452-3538

Dr. W. Varty
Environmental monitoring; Assessing hazard; Advice on timing; Evaluation of results.

Forest Protection Ltd. (FPL)
Mr. H.J. Irving, Managing Director
P.O. Box 1030
Fredericton, N.B. E3B 5C3
Tel: (506) 357-3366

Dr. Frank E. Webb
Non-profit organization for carrying out forestry spraying research related to drift.

Research & Productivity Council of New Brunswick (RPC)
P.O. Box 6000
Fredericton, N.B. E3B 5H1
Tel: (506) 455-8994

C.J. Wiesner, Chemistry Department
Have done work with FPL

University of New Brunswick
Department of Chemical Engineering
Dr. J.J.C. Picot
Fredericton, N.B.
Tel: (506) 453-4520

University has done work with FPL
Laser probe for droplet characteristics.

Québec Ministère de l'Energie et des Ressources
Direction de la conservation
175 rue St-Jean
Québec, P.Q. G1V 1N4
Tél: (418) 643-4670

M. Michel Pelletier
Dr. J.G. Davidson
Forestry pest management operations
Don't do research, although some testing, e.g. effect of carrier (water, oil base) on nozzle delivery.

National Research Council of Canada
National Aeronautical Establishment
Building U-61, Uplands
Ottawa, Ontario K1A 0R6

Boom design, modelling of near and far field droplet movement, airborne gas chromatograph, flying spot scanner for droplet pattern analysis, uniform drop generation, spread factor determination, droplet impaction, aerial dart seeding.

Dr. G. Lindberg, Director 993-2427
Dr. S.R.M. Sinclair, Head, Flight Research Laboratory 998-3071
Dr. A.M. Drummond, Flight Research Laboratory 998-3567
Dr. C.D. Hardwick, (air navigation systems)
Dr. R.S. (Dick) Crabbe (drift monitoring)
Mr. Slack (droplet generator)

Canadian Forestry Service
Environment Canada
Place Vincent Massey
Ottawa, Ontario K1A 1G5
Tel: (613) 997-2175

Dr. C.H. Buckner, Program Leader, CANUSA Spruce Budworm Program. Research is carried out at field establishments, e.g. Forest Pest Management Institute.

Petawawa National Forestry Institute
Chalk River, Ontario

Aerial seeding, aerial burning, fire detection (remote sensing).

Forest Pest Management Institute (FPMI)
Canadian Forestry Service
P.O. Box 490
Sault Ste. Marie, Ontario P6A 5M7
Tel: (705) 949-9461

Dr. Jack A. Armstrong
Dr. Nigam
Ms. K.M.S. (Alam) Sundaram (spray physics)
Mr. B. Leo Cadagon (efficacy)
Mr. J.C. Edwards (helicopter application)

Saskatchewan Research Council
30 Campus Drive
Saskatoon, Saskatchewan S7N 0X1
Tel: (306) 664-5417

Dr. John Maybank, Director, Environment Section
Dr. Ken Yoshida
Previous work on drift monitoring, presently working on chemical absorption by air spray crews.

Lethbridge Research Station
Agriculture Canada
Lethbridge, Alberta T1J 4B1
Tel: (403) 327-4561

Dr. Bill Charnetski
Spray penetration into crop canopy, aircraft vs. ground equipment.

Saskatoon Research Station
Agriculture Canada
107 Science Crescent
Saskatoon, Sasktchewan S7N 0X2
Tel: (306) 343-8214

Computerized data base on spraying references, including aviation.
Dr. K.S. McKinlay
No research work.

Alberta Agriculture
7000 - 113th Street
Edmonton, Ablerta T6H 5T6

Terry Footz
Subjective field observations of effectiveness of aerial spraying.

Lakeland College, Vermilion Campus
Vermilion, Alberta

Mr. Roger Lauurin
School for aerial spray operators. No research work.

B.C. Ministry of Forests
Parliament Buildings
Victoria, B.C.

Jenji Konishi, Forester (seeding)
Camille Apt, Forestry Engineering Division
Development of equipment for aerial seeding

International Range Remote Sensing Ltd.
1355 Nanaimo Street
Kamloops, B.C. V2B 2W1
Tel: (604) 376-8684

Dr. Kent Watson
Remote sensing using 35 mm film images.

Land Resource Research Institute
Agrometeorology Section
Research Branch, Agricutlure Canada
Ottawa, Ontario K1A 0C6
Tel: (613) 995-9039

Dr. A.R. Mack
Remote sensing, aircraft and satellite

Paper No. IX-B

FUTURE RESEARCH AND DEVELOPMENT REQUIREMENTS
PHYSICAL SCIENCES

G.M. Lindberg
National Aeronautical Establishment
National Research Council of Canada
Ottawa, Ontario K1A 0R6

ABSTRACT

This paper will propose a research and development program in agricultural spraying intended to advance the state-of-the-art of both the science and the technology of aerial spraying. Proposed program goals are:

I) To achieve an aerial spray research program in which cost, efficiency and predictability of deposition, and the assessment of by-stander and off-target wind-borne exposure are key elements. The program will stress basic research and innovation.

II) To define design parameters related to increased aircraft performance, effectiveness and safety, with particular reference to the overall spray system, flight instrumentation, and auxiliary spray equipment.

III) To develop operational and tactical guidelines for use by small and large-scale operators; these are intended to result in lower cost, increased spray efficacy, and the encouragement of innovative means of depositing spray.

The paper will also address the resources required to carry out such a program, identifying resources presently available to carry out the studies and what new resources will be required.

INTRODUCTION

Spraying is vital to ensure the maximum utilization of our agricultural and forestry resources. It enhances the rate of growth and protects the quality of these important natural resources. Aerial spraying, in particular, has become increasingly important in Canada.

Aerial spraying enables vast areas to be covered quickly and crops may be treated at the optimum time. Pesticides can be placed on growing crops without the damage caused by land vehicles. More uniform coverage may be obtained. Therefore, the amount of aerial spraying done in agriculture should increase. Two major impediments to the expansion of aerial spraying exist. Firstly, the cost of aerial spraying has increased due to more expensive chemicals, more expensive equipment and more expensive fuel. Secondly, the problem of "uncontrolled" spray drift poses an environmental hazard. Regulatory agencies are imposing more severe restrictions on spray activities, often based on incomplete data. Environmental groups continue to lobby to stop all aerial spraying.

This paper proposes a comprehensive research and development program that addresses both issues. A better understanding of the total spray mechanism should result in more efficient spraying, reducing costs and unwanted drifting. Rather than dwelling on detailed problems to be solved, it will outline, in broad terms, the necessary size and scope of an effort that can be expected to yield significant improvements to the present state-of-the-art.

This paper assumes that the natural scientists will tell us (the physical scientists) where the spray should be delivered (top of canopy, base of canopy, etc.), the optimum size of spray droplet, how much pesticide must be delivered and when spraying is most efficient. It also assumes a close interaction with these same scientists since neither side can operate in a vacuum.

PROGRAM GOALS

The following are proposed program goals for a comprehensive spray research program.

1) To achieve an Aerial Spray Research Program in which cost, efficiency and predictability of deposition, and the assessment of by-stander and off-target wind-borne exposure are key elements. The program should stress basic research and innovation.
2) To define design parameters related to increased aircraft performance, effectiveness and safety, with particular reference to the overall spray system, flight instrumentation, and auxiliary spray equipment.
3) To develop operational and tactical guidelines for use by small and large-scale operators; these are intended to result in lower cost, increased spray efficacy, and the encouragement of innovative means of depositing spray.

PROGRAM OBJECTIVES

To achieve the above goals, a number of program objectives have to be delineated. The following list of objectives, while not necessarily complete, is a good outline of objectives for this program.

1. Acquisition and instrumentation of a "typical" agricultural spray aircraft for use in an experimental spray program.
2. Acquisition and development of a comprehensive set of field instrumentation and sampling and analysis techniques for use in an experimental spray program.
3. Establishment of a wind tunnel/computational modelling program to investigate wake vortex and ground interactions in general and for studying the particular experimental airplane configuration.
4. Establishment of a spray nozzle characterization facility and/or development laboratory for the study of spray formulations and the optimization of nozzle droplet distributions.
5. Delineation and conduct of a comprehensive experimental spray program, commencing with very controlled conditions. This would include the generation and measurement of droplet size spectra and the study of aircraft wake and slipsteam flows in the ground effect, with and without vegetation, the study of wind-borne spray transport and the study of spray interaction with target elements, including by-stander and off-target impact.
6. Expansion of the program to include rotary-wing and different operational aircraft.
7. Development of innovative forms of spray application, i.e., ultra-light aircraft, powered lift, modifications to wing load distribution, etc.
8. The study of spray aircraft performance, stability and control related to flying qualities, manoeuvre capability, etc., including the study of stall/spin problems.
9. Studies of spray pilot safety and workload. The development of a "head up" flight display for agricultural pilots and the development of new navigation aids.

10. Definition of swath width, and allowable separation between flight lines. Assessment of incremental spraying methods with reference to crosswind and drift.
11. Development of economic models that can be used to assess and compare available equipment and the development of requirements for new types of aircraft.
12. Development of standards for by-stander and off-target protection from spray contamination and the development of minimum offset requirements for safe, effective spraying.

RESOURCE NEEDS

The comprehensive program outlined above will need significant resources. A minimum of ten to fifteen researchers will be required, including an applied mathematician, an instrumentation engineer, a micro meteorologist, aeronautical engineer/pilots and chemical, electronics and mechanical technologists. This excludes the requirements for maintenance, servicing and modifications of the experimental aircraft.

Facilities needed include experimental aircraft, one or more controlled test sites, meteorological instrumentation, spray sampling equipment, computation facilities, laser cloud mapping instrumentation, nozzle test facilities and wind tunnels.

The capital costs for setting up the program would easily exceed $3,000,000 and the operating costs per year will approach $1,000,000.

Clearly a comprehensive program will be expensive and careful cost benefit analyses will need to be carried out to justify the effort.

CONCLUDING REMARKS

A comprehensive spray research program has been outlined and it is evident that it can be a costly process. Several questions need to be answered before it can be established.

Firstly, someone must "crystal ball gaze" and predict whether such a program will lead to significant improvements or whether efficacies will only be marginally improved. In these times of scarce resources, cost benefit analyses must be carefully carried out.

Related to this question is the status of regulations. It is easy to envision a scenario where regulations are changed to force the spray community to more clearly establish long range spray drift patterns, etc. before aerial spraying is permitted. In such a scenario, a research program becomes mandatory if aerial spraying is to continue. This may change the whole cost benefit analysis.

Another related question is the fiscal ability of the operations community to adopt new equipment and/or techniques if significant capital costs are involved. Can the industry afford a "better mousetrap"?

If the cost benefit analyses indicate that the program should be established, there remain three questions, who should provide the resources, who should carry out the program and where should it be conducted.

Resources are a major problem. At the federal level, at least four agencies, Agriculture Canada, the Canadian Forestry Service of the Department of the Environment and the National Research Council of Canada have mandates that would permit them to carry out such a program and indeed have ongoing research programs in this area. However, in these times of limited resources and fixed or declining staff levels, it is not clear that additional existing resources can be diverted to this task. The allocation of new resource depends upon the political will of the Government of the day.

Provincial governments also have responsibilities in this area and several are actively promoting research and development notably New Brunswick, Quebec and Saskatchewan. Perhaps some new resources from them might be forthcoming.

Intertwined with the question of resources is the question of who should carry out the program. It has been argued that a new program should be built upon an existing program, say at N.R.C. in Ottawa. While this might be attractive from a lower cost and existing skills point of view, it might be better to have the program in one or two regional locations to more closely interact with the operators.

Finally, there is the perennial question, should this program look at both agricultural and forestry applications or concentrate on one area. Again, differences of opinion must be resolved.

This paper has outlined a comprehensive program of research and development in the physical sciences of aerial spraying. While it may not be complete, it does indicate the major problem areas and does scope the effort involved. This has been the easy part of the task. The greater challenge will be to establish such a program.

ACKNOWLEDGEMENTS

Most of this paper is based upon the work of others, notably the work of an N.A.E. Task Force consisting of R. Wickens, A. Barszczweski, R. Crabbe, A. Drummond, L. Elias and P. Kumar. I am most endebted to them for their efforts.

This paper presents the personal opinions of the author and does not reflect official NRC policy.

Paper No. IX-C

FUTURE RESEARCH AND DEVELOPMENT NEEDS NATURAL SCIENCES

J.R. Hay
Research Station
Research Branch, Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan S7N 0X2

The main uses for aircraft in agriculture will be for 1) remote sensing, 2) seeding, 3) application of fertilizers, and 4) application of herbicides, insecticides, fungicides, biological control agents, and growth regulators.

As noted in the paper by Dr. Mack, considerable progress has been made in development of equipment for remote sensing, both from aircraft and satellites. As these improvements continue, there will be a need for various disciplines, agronomists, pathologists, etc., to participate in ground truthing and the application of the new technology.

Aerial seeding has been done successfully in Canada. The main interest is for use in wet years, but it has been shown that some incorporation of seed by harrowing, etc., is required for consistent results. Its use is limited to small seeded crops, such as canola and forage crops. With larger seeds, aerial seeding becomes too costly. Agronomists at western universities and research stations could cooperate in tests on aerial seeding if the aircraft were available.

Application of fertilizer by aircraft in Canada is very limited. Most fertilizers must be incorporated with the seed and the bulk of fertilizer required makes application by this method uneconomical. Application of some fertilizers to uneven grassland may have some value, perhaps in B.C. or in Eastern Canada. Again, soil scientists are available to conduct such tests if suitably equipped aircraft were available.

By far the greatest potential for the use of aircraft in agriculture is for the application of agricultural chemicals. At present 80% of such aerial application of pesticides occurs in the prairie provinces where between 5-10% is applied by air. Much of the aerial application in Eastern Canada is done for the control of fungus diseases (i.e. in potatoes), with several applications being made per growing season. Although the percentage is low, it amounts to about 3,000,000 hectares which is close to the amount of aerial applications done in forestry.

The major disadvantage of aerial application of pesticides is the problem of drift. Using existing technology with conventional ground rigs, drift can be reduced to less than 1%. With aircraft and Spraycoupes, drift is usually about 10% or higher.

There are some important advantages to aerial application. Pesticides can be applied to fields that are too wet for ground application. The speed of application, ca 80 hectares per hour, is considerably higher than for conventional ground equipment, although with large floaters it is possible to treat 30 hectares per hour.

The aircraft is admirably suited to applications of pesticides at advanced stages of crop growth when ground equipment would cause considerable damage. Typical examples of the need for this are:

1) Bertha armyworm — insecticides are applied at pod stage.
2) Sclerotinia -- fungicides are applied late in the season.
3) Wheat midge — insecticides applied at heading.
4) Sunflower moths -- insecticides applied to flowers.
5) Desiccation of crops to facilitiate harvesting.
6) Brush control in pastures.

Application of pesticide by air requires an integrated management system, the same as for ground equipment. Monitoring will be a key to success to ensure that chemicals are applied at the optimum time and in such a way that effect on natural parasites and predators is minimized. Weed scientists, entomologists, and plant pathologists are already active in this area.

Another area requiring work is the determination of optimum drop size, pesticide concentration within the drop and the number of drops per unit area. The optimum drop size for ground and aerial application has to be determined. The desire for optimum efficacy may have to be compromised by the need to minimize drift.

There are several units described in the literature which produced controlled drop sizes in the lab. Thus the equipment is available but people and material resources are required to get the work done.

Once we know the desired drop size for various formulations, there is the need to develop the equipment for their applications in the field.

This kind of work is going on around the world. What we need is a unit in Canada that will evaluate and refine the new technology to meet Canadian conditions. Centres could be supported in Eastern Canada, i.e., Fredericton, and in Western Canada, i.e., Saskatoon since some expertise already exists at these locations. The members of the Western Spray Group working out of Saskatoon and Regina have the expertise and facilities to do drift, deposition and mass balance studies. The University of Saskatchewan has a wind tunnel. What is lacking is an aircraft for conducting aerial trials and consistent supply of funds for a concerted research program. Researchers would also need laser droplet measuring systems for monitoring.

Probably the most serious research and development deficiency in the area of aerial application is the development of efficacy data. Rates, volumes, etc., that are used with ground rigs can be simulated in small (i.e. 5 × 2 m) plots that will produce results that can stand up to rigorous statistical analyses.

It is not easy to simulate aerial application of pesticides for small plot tests. The aircraft travel at almost 160 $km.h^{-1}$, and apply low volumes (10 $\ell.ha^{-1}$) and produce considerable turbulence, making application to small plots very difficult.

Thus, it is logical that rates, volume, and methods of applying pesticides should be developed for conventional ground rigs first. Once these parameters have been established, then it will be necessary to confirm that equally good results can be obtained with Spraycoupes, floaters and aircraft.

Chemical companies are already doing some of this work to satisfy registration requirements. Unfortunately, these data are not readily available to the public. If there was an establishment where such studies could be contracted, unbiased work would be done and the data would be available to those responsible for making recommendations to the public and to extension workers. Work would have to be done to establish experimental designs for these trials that will generate statistically sound data.

In summary then, we have a need for centres in Eastern and Western Canada to conduct research on application of pesticides. These centres should be able to do work with ground equipment, but should also be capable of doing work on aerial application. One obvious centre for such work is Saskatoon/Regina where considerable expertise and equipment already exists.

With respect to aerial application, the major requirement is for a suitable aircraft and nurse truck that could be dedicated to this work for a 3 or 4-month period each year. Although of lower priority, this aircraft could be used for research on seeding and application of fertilizers. Another major deficiency at the moment is a laser droplet measuring system. Also required is a consistent supply of operating money to ensure continuity of the research.

POSTER PAPERS

The following 11 submitted papers were displayed at Poster Session during the Symposium.

Poster Paper No. 1

THE NAE DROPLET GENERATOR

W.E. Slack
National Aeronautical Establishment
National Research Council
Ottawa, Canada
K1A 0R6

ABSTRACT

A droplet generator developed for laboratory use at NAE is described. To generate droplets a loud speaker driven extractor needle is immersed in the pendant drop. Subsequent pulsing of the speaker extracts the needle forming a ligament which will decay into a droplet. The droplets are sized using stroboscopic photomicrography. The droplet size can be changed by varying the amplitude of the speaker pulses and the diameter of the extrator needle. The mechanism of droplet formation is discussed and photographs of ligament decay are presented.

The droplet generator works well on both oil and water based pesticides and the majority of its applications to date have been related to agriculture and forestry pest control. In spray deposit assessment studies the droplet generator is being used to determine the relationship between the size of pesticide droplets and their respective deposit stains. The droplet generator has also been used in laboratory toxicology experiments as a means of applying discrete pesticide droplets to insect larvae. These applications and the results are described.

INTRODUCTION

The NAE Droplet Generator is a device designed to produce and photographically record for subsequent sizing discrete droplets in a laboratory environment. It is also a useful instrument for observing the breakup or collapse of fluid ligaments or to dispense minute quantities of fluid.

Description of the Droplet Generator

The droplet generator consists of a pendant drop generator, a droplet extractor, a photographic recording system and an electronic control system (Fig. 1).

Pendant Drop Generator

The source of fluid for the droplets is a pendant drop. Fluid is supplied to a central port in a 6.3 mm diameter horizontal disc and collects on the disc to form a pendant drop. The pendant drop is in the order of 10^6 times the size of the droplets produced and therefore a continuous supply of fluid is not needed while generating droplets.

Droplet Extractor

The droplet extractor consists of a horizontal extractor needle connected by a drive shaft to the cone of an audio speaker. By controlling the polarity and amplitude of electrical pulses to the speaker, the tip of the extractor needle can be driven into or pulled out of the pendant drop. The speaker currently being used is a 25 watt 8 inch diameter speaker. With positive and negative pulses of 8 volts (6.5 watts), it produces an extractor needle movement of ± 4.2 mm (Fig. 2).

Power for the speaker is supplied by a dual variable voltage power supply. One half of the power supply provides the positive pulses to immerse the needle in the pendant drop while the other half provides the negative pulses to extract the needle. A conventional multimeter is used to set the amplitude of the pulses accurately.

The extractor needles are interchangeable and needles of various diameters, ranging from 98 microns (µm) to 700 µm, have been used.

Photographic Recording System

The droplet generator includes a photographic recording system to record photographic images of the droplets for subsequent size determinations. The camera used is a conventional 35 mm Pentax Spotmatic with a motor drive film advance and a remotely operated shutter attachment. Since the droplets being photographed are small, considerable photographic magnification is required before they can be accurately sized. This requirement is met by using an 8X microscope objective lens and a 2.5X microscope eye-piece in lieu of the conventional photooptics to achieve a magnification of 20.

The formation of a droplet is a dynamic event and short exposures are required to obtain sharp droplets images. A strobotac and a stroboslave, operating in a single flash mode are used and provide a 5 microsecond (µsec) exposure.

Droplet Generator Controller

The controller was developed specifically for the NAE Droplet Generator and its function is to control and sequence all the events associated with generating and photo-recording a droplet. It can be operated in a "single droplet" mode or in a "continuous" mode generating droplets at various preset rates of up to 3 droplets per second. The portion of the controller which operates the strobe lights contains an adjustable digital delay timer (1000, 50 µsec steps) to operate the lights at the appropriate instant.

OPERATION OF THE NAE DROPLET GENERATOR

Adjusting the Extractor Needle Position

The criterion used to set the extractor needle position relative to the pendant drop is an arbitrary one, but one which has provided consistent results. The needle is positioned vertically 1.0 mm below the pendant drop base so that it will enter the relatively flat side of the drop. It is positioned laterally so that the tip of the needle will be centered in the pendant drop when a full amplitude (8 volt) "IN" pulse is applied to the speaker.

Generating Droplets

For any given extractor needle, a range of droplet sizes may be generated by varying the amplitude of the "IN" and "OUT" pulses to the speaker. The range of droplet sizes which can be expected for oil based formulations is

$$D_n/3.D_d.D_n$$

and for water based formulations is

$$D_n/6.D_d.D_n/2$$

where: D_d - diameter of the droplet
D_n - diameter of the extractor needle.

The time required to form a droplet varies considerably with changes in the "IN" and "OUT" pulse amplitudes and the delay timer must be set to photo record at the appropriate time.

APPLICATIONS OF THE DROPLET GENERATOR

The NAE Droplet Generator was developed specifically for biological applications. It has been used to treat insect larvae and foliage with specific dosages of pesticide and as a calibration tool in assessing aerial spray deposits. The droplet generator also appears to be suitable for studies on liquid ligament break-up or collapse. Government agencies in several other countries have adapted it to their needs.

Dispensing Minute Quantities of Fluid

The droplet generator can be used as a tool to dispense minute quantities of fluid (i.e. in the order of 10^{-6} microlitres). It has been used to treat spruce budworm larvae with specific dosages of pesticide to determine required spray parameters for adequate insect control (Fig. 3). It has also been used as a means of depositing discrete droplets on foliage in studies to determine the foliage area wetted by various sizes of droplets.

Spread Factor Calibrations

When monitoring an aerial spray, it is customary to place sampling cards in the area being sprayed to collect a sample of the droplets pesticide distributed. The cards retain the stains produced by the droplets. For subsequent pesticide accounting it is necessary to know the relationship between the size of the stains and the droplets that produced them. The droplet generator is used to produce controlled size droplets of the appropriate pesticide. The droplets are collected on sampling cards and the stains are sized by the NAE Flying Spot Scanner/Analyser. The computer outputs for the droplet and stain sizes are combined to produce a mathematical relationship between the size of a droplet and the size of the stain it will produce on a particular type of sampling surface. The mathematical relationship developed is typically:

$$D_d = C + bD_s$$

where: D_s - stain diameter (μm)
C - a constant
b - the slope of the curve

The slope confidence at the 90% interval is typically ±0.3%.

Studying Ligament Collapse

Figure 4 is a series of photographs showing the formation of a droplet. The process of forming a ligament and its collapse to form a droplet is extremely consistent. This photographic series is not a high speed movie; it is 20 photographs of 20 different droplets. In each case the photo exposure has been delayed by the time shown on the photograph.

With different combinations of "IN" and "OUT" pulse amplitudes the ligament may break free from the pendant drop and the extractor needle simultaneously or from either end first. In Figure 4 it breaks free from the needle first and the needle end of the ligament starts collapsing to form the droplet. This portion of the ligament starts moving towards the pendant drop. When the pendant drop end of the ligament finally breaks free, it too starts collapsing to form a droplet and this portion of the ligament moves away from the pendant drop. Since the needle end of the ligament started forming a droplet first, its mass is greater than the other portion of the ligament and the resulting droplet has a horizontal velocity towards the pendant drop. Similarly if the ligament breaks free from the pendant drop first the resulting droplet is given a horizontal velocity away from the pendant drop.

Figure 4 also shows that if the droplet contacts the pendant drop, both the droplet and the pendant drop distort but the droplet will bounce free from the elastic pendant drop surface. In cases where the ligament breaks free from the pendant drop first it is possible for the resulting droplet to overtake the extractor needle. Although the extractor needle is covered with fluid it cannot distort, as the pendant drop did, and the droplet is "captured" by the needle.

In Figure 4 there is also evidence of another phenomenon; namely, the instability of a cylindrical liquid jet or ligament. In Figure 4 there is evidence that the ligament was trying to break up; however, the ligament did collapse into a discrete droplet before the break-up could occur.

Under certain conditions the separation of the second end of the ligament may be delayed considerably. When this occurs the ligament will break-up, forming multiple droplets, before it can collapse to form a single droplet.

RESULTS WITH THE DROPLET GENERATOR

Droplet Sizes Produced

The parameters which have a significant effect on the size of the droplets are:

- the diameter of the extractor needle
- the amplitude of the "IN" pulse to the speaker (i.e. the immersion depth of the needle in the pendant drop)
- the amplitude of the "OUT" pulse to the speaker (i.e. the velocity at which the needle is extracted from the pendant drop).

The generator, with extractor needles ranging from 98 µm to 700 µm has produced droplets ranging in size from 15 µm to 800 µm.

Droplet Size Consistency

Figure 4 appears to be a series of photographs of the formation of the same droplet. Actually, as previously indicated, each photograph is of a different droplet. Each photo was taken at a slightly later time in the droplet formation process. The droplet formation process illustrated by the photo set indicates the consistency of the droplet formation process. Tests have been carried out to determine the size consistency of the droplets and typical results are listed in Table 1.

TABLE 1

Droplet Size Consistency

Number of droplets measured	24
Mean drop diameter	179.34 μm
Range	5.30 μm
Standard deviation	1.20 μm

Accuracy of Droplet Size Measurements

The source of errors in measuring droplets and their estimated magnitude are listed in Table 2.

TABLE 2

Errors in Droplet Size Measurements

Source of Error	Magnitude of Error
Photographic magnification	± 0.38 %
Lens resolution	± 0.9 μm
Film resolution	± 1.0 μm
Measuring accuracy	± 0.1 μm

Tests to determine the error due to the sum of the last three items in Table 2 indicate an error of slightly over ±1 μm. For droplets in the 20 to 150 μm range the overall droplet sizing error is approximately ±1.5 μm.

CONCLUSION

The NAE Droplet Generator is a device which will produce discrete droplets with fluids of various viscosities (i.e. heavy fuel oils or water). It has been used to generate droplets ranging in size from 15 μm to 800 μm. Images of the droplets produced are photographically recorded and can subsequently be measured within ±1.5 μm. Once the generator has been set to generate a specific size of droplet it will continue to produce droplet diameters with a standard deviation of less than 1%.

The consistency of the droplet formation process also makes the generator a suitable instrument for observing fluid ligament breakup or collapse.

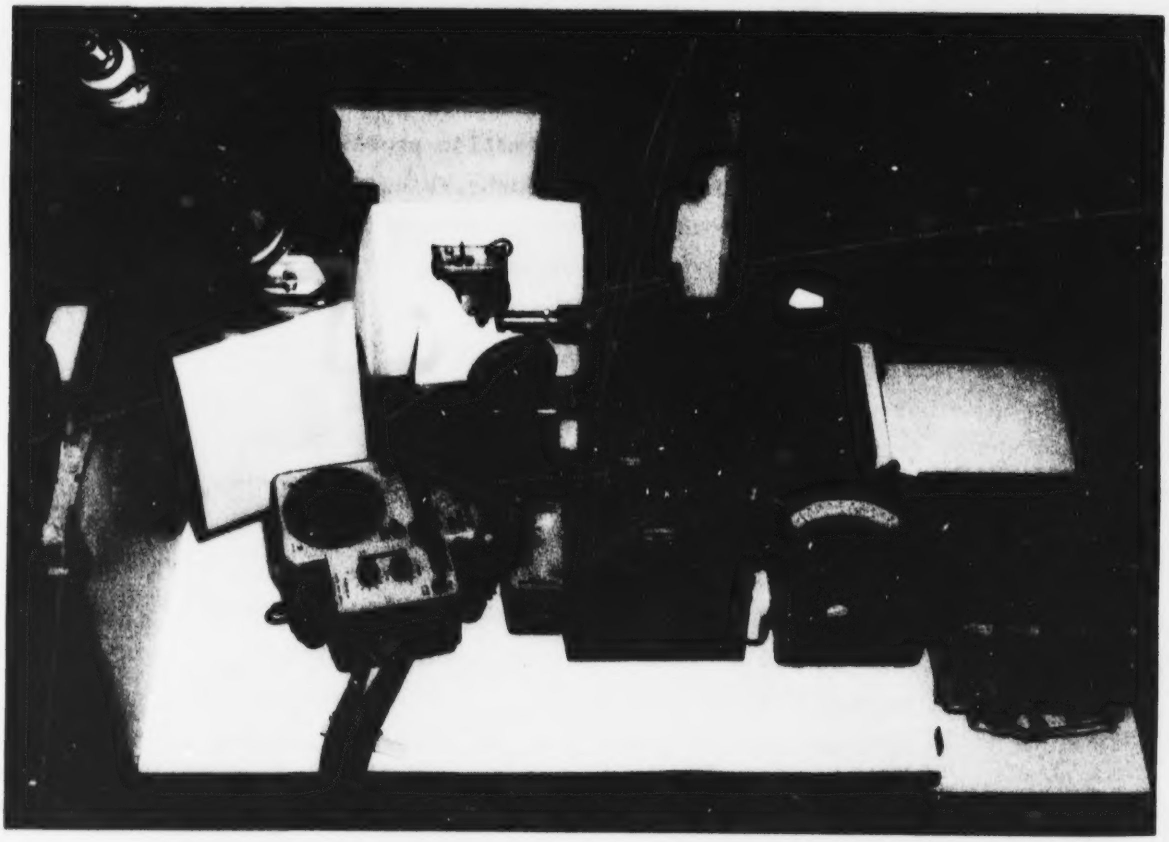
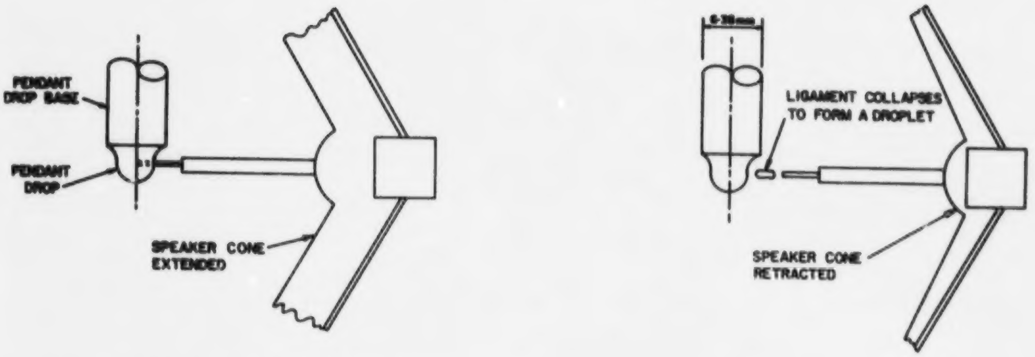


Figure 1. The NAE droplet generator.


PENDANT DROP BASE
PENDANT DROP
SPEAKER CONE EXTENDED
LIGAMENT COLLAPSES TO FORM A DROPLET
SPEAKER CONE RETRACTED

SPEAKER ENERGIZED-NORMAL POLARITY

APPLYING A NORMAL POLARITY SIGNAL TO THE SPEAKER CAUSES THE EXTRACTOR NEEDLE TO PENETRATE THE PENDANT DROP.

SPEAKER ENERGIZED-REVERSE POLARITY

REVERSING THE POLARITY OF THE SIGNAL TO THE SPEAKER CAUSES THE EXTRACTOR NEEDLE TO BE WITHDRAWN FROM THE PENDANT DROP PULLING WITH IT A LIGAMENT OF FLUID WHICH COLLAPSES TO FORM A DROPLET.

Figure 2. Method of forming droplets.

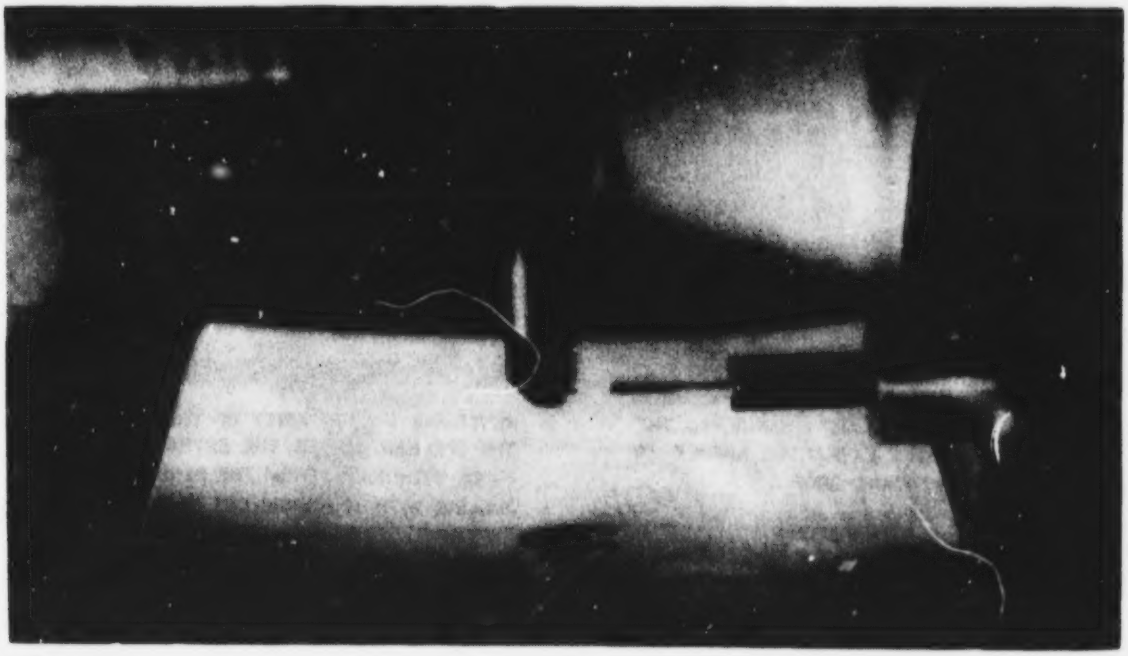


Figure 3. Dispensing droplets on to a spruce budworm.

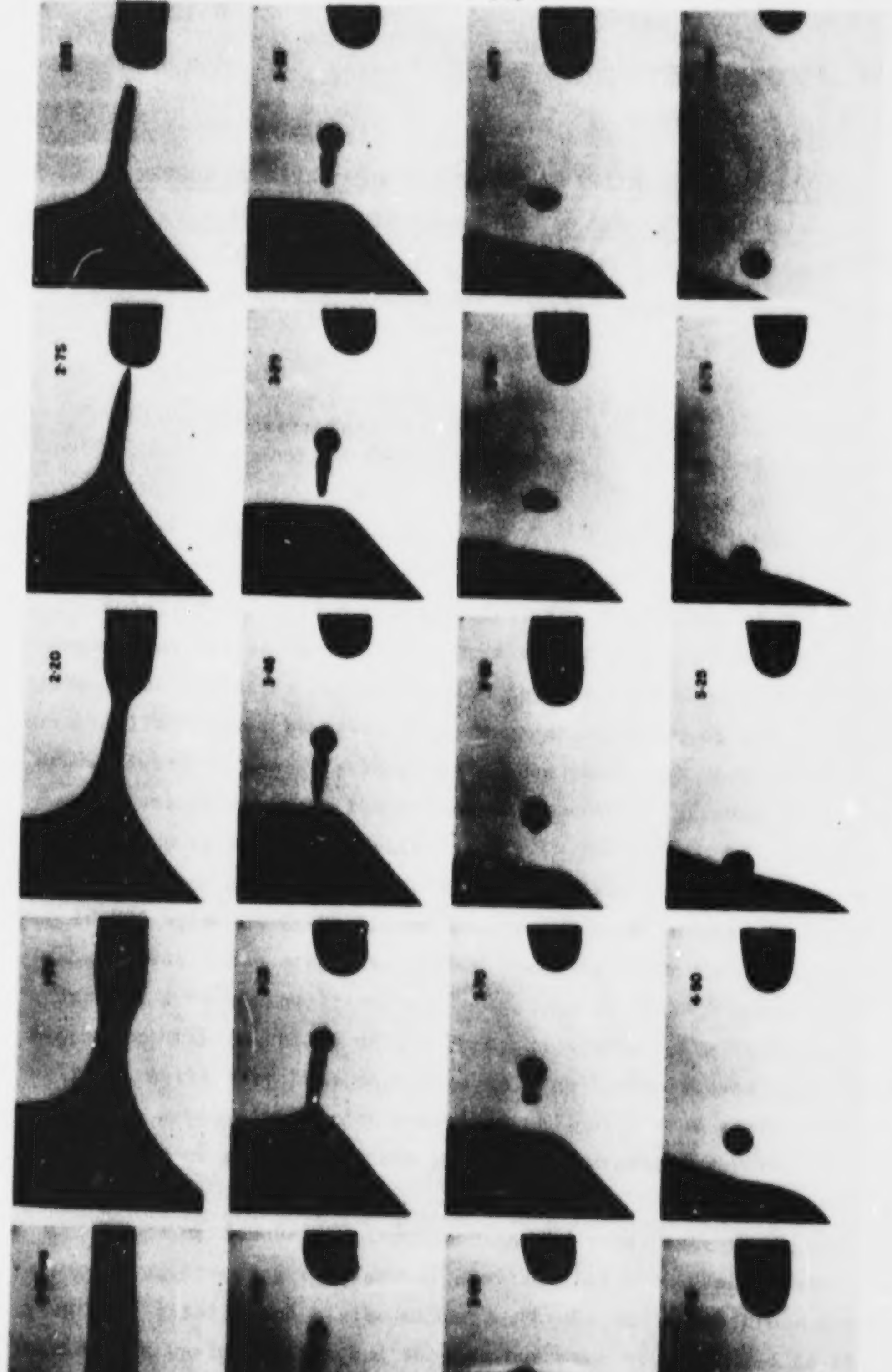

2·75
2·20
5·25
4·90

Figure 4. Ligament Collapse to Form a Droplet.

Poster Paper No. 2

A METHOD OF USING REMOTE SENSING TO ESTIMATE PRODUCTIVITY LEVELS IN SEEDED RANGELANDS OF WESTERN CANADA

D.H. McCartney
Agriculture Canada Research Station
Melfort, Saskatchewan
S7N 0X2

M.D. Thompson and R.V. Dams
Intera Environmental Consultants Ltd.
Calgary, Alberta

INTRODUCTION

Remote Sensing is a valuable tool for evaluation of species composition and productivity in grazing and rangeland areas. The purpose of the study was to develop low-cost techniques which could eventually be used by pasture or range managers to assess productivity of Canada's Parkland seeded pastures. A secondary purpose was to evaluate the use of 35 mm colour infrared photography as a remote sensing tool.

The study site of 1000 acres of roughland pasture is located on 20,000 acres of Saskatchewan Government pasture near Melfort, Saskatchewan. The area lies within Canada's Aspen Parkland, extending from southwestern Manitoba, central Saskatchewan and Alberta to the foothills of the Rocky Mountains. The terrain is rolling, soils vary from dark gray to gray Luvisols, and vegetation is mainly aspen with seeded grassland and cultivated grain fields. Wet sloughs or marsh areas and many stone outcroppings are present.

The major forage species found in the study area were bromegrass, creeping red fescue, Russian wild rye, quackgrass, blugrass, alfalfa and alsike clover. Shrubs and aspen trees were present in various sizes and amounts but were not included in the biomass data collected. Distribution of these species were heterogeneous across all the pastures. The average rainfall in this area is approximately eleven inches. Emphasis was placed on data acquisition and analysis techniques which could be made available to pasture or range managers without excessive cost or over-sophistication, thus considering an eventual operational application for results of this research.

The ground data and remote sensing imagery were obtained in early June, mid-July and late August in 1979, 81, 82 and 83. Forty-five to fifty sampling sites were selected to represent the different pasture types from across the 15,000-acre pasture. These were represented by:

1. Old Pastures: lowest biomass (heavy grazing), mainly creeping red fescue;
2. New Seeding: moderate biomass, mainly intermediate wheatgrass and other coarse grasses; and
3. Intermediate Stand: highest biomass, mainly bromegrass and alfalfa.

At each sampling site 12 or 18 (.25 m^2) clip plots were taken. Every third plot clipped was separated into coarse grasses, fine grasses, weeds, legumes, and litter. All the sample material from all plots was dried and weighed in order to determine yield data.

In addition, ground photographs were taken and data forms completed at each site with information on vegetation height, percent cover (ocular estimate), abundance of litter, stones, and other features which could influence the resultant spectral signature of each site. Grazing records for the fields were also obtained.

The locations of each of the 0.1 ha study sites were marked on the ground for later identification on the remote sensing imagery. The most successful ground marking technique utilized 1.2 m square red plywood targets placed at the centres of the sites, and 0.6 m square red targets placed 17.8 m from the site centres. The red site markers thus appeared yellow on the infrared photo. This permitted the site center marker to be distinguished from the edge marker, the entire circular site (in which the samples were randomly clipped) to be noted on the photographs as judged from the radius distance, and the photo scale to be accurately determined.

In 1979 the program was started using 23 cm color infrared photography obtained from the Canada Centre for Remote Sensing, Falcon Fanjet, at a scale of 1:8,000 and 1:24,000 and Landsat MSS data at 1:250,000. These were all paper prints and film positives. Later in 1981 35 mm colour infrared (CIR)hotography was obtained of the sites and compared to the 23 cm material. This lower cost 35 mm photography was obtained using a Pentax LX camera with a 50 mm F1.7 lens and motor drive. The 35 mm camera system was mounted with a Meyer camera mount out of the left window of a Cessna 172. Kodak Ektachrome infrared slide film type 2443, ASA 125 was used with a Wratten 12 filter. Stereo infrared slide and 8 × 10 Cibachrome print enlargements were obtained at 1:2,500, 1:50,000, 1:20,000 and 1:40,000 scale at the same time as the ground sampling was collected.

DATA ANALYSIS METHODS AND PROGRAM DEVELOPMENT

The data analysis methods evolved through the three phases of the study to be time-efficient and to produce accurate results for operational work. Generally, the approach involved three stages: (1) analysis of the ground data; (2) interpretation of the remote sensing data; and (3) statistical analysis of the two data sets to evaluate accuracy in productivity prediction.

In the ground data analysis, biomass and species composition data were used to group the pastures into classes. This allowed the mean characteristics of grouped pastures to be more easily, rapidly and meaningfully evaluated, and compared to the remote sensing interpretation results. Three pasture types by species were identified in 1979, six types in 1981, and two sets of pasture types in 1982. In the latter, analyses were carried out first using the three major pasture types identified prior to ground sampling (i.e., Old Pastures, New Seeding, Intermediate Pastures), which were related both to species composition and to biomass level. A second set of analyses was carried out using pasture types based primarily on species composition (by weight) as in previous years, and included five pasture types (Coarse Grass, Coarse Grass/Weed, Coarse Grass/Legume, Coarse Grass/Fine Grass and Mixed Grass and/or Forbs).

Interpretation of the remote sensing data was carried out by one interpreter in 1979, to evaluate the usefulness of a variety of interpretation parameters for predicting biomass. As colour and texture were the most important, the 1981 analysis evaluated these parameters; several methods of combining the remote sensing interpretation results were tested statistically (a dichotomous key for predicting biomass level and pasture type, and several indices which combined colour, pattern and texture in weighted proportions for biomass prediction). However, none of these provided better results than the simple interpretation of colour and texture, so they were omitted from the 1982 work.

The colour interpretation was standardized through use of the USDC (1976) NBS-ISCC colour manual. Each 35 mm slide was projected onto a white board, and the colour chips directly compared with the colour on the slide. This method is direct, simple and inexpensive, as it involves neither production of paper prints from the slides, nor looking back and forth from a colour chip to a slide under a stereoscope. Colours were grouped into five classes ranging from green, yellowish-pink, pinkish-white to pink or red.

Texture was interpreted from the original 35 mm CIR slides using 8-power oculars on a Wild-Heerbrugg ST-4 mirror stereoscope. Table 1 shows the five textural classes used in 1981 and 1982. These were expanded in 1982 into 17 classes; since the presence of different textures within the 0.1 ha circular sites could easily be noted, the interpreter could estimate texture in 25% increments (e.g., 50% Coarse, 25% Coarse-Medium, 25% Medium).

The interpretation was carried out at two photo scales; 1:5,000 and 1:20,000. Since the analysis showed that the larger scale provided better productivity information, photographs at an even larger scale (1:2,500) were obtained for testing.

Finally, statistical testing of the 1982 interpretation results was carried out to evaluate the accuracy of biomass prediction. The influence of time of year (i.e., June, July), photo scale (1:2,500, 1:5,000), method of interpretation (i.e., use of colour, 5-class texture, 17-class texture), and type of interpreter were tested. The latter was included to evaluate the necessary qualities of an operational interpreter (i.e., knowledge of the study area and/or skill in photo interpretation), since this would affect how the technique could be used operationally in the future.

Over the three program phases, a number of statistical tests were applied to the data; the most useful were Kendall's tau (Blalock 1960), used primarily in 1981, and the Eta coefficient (Mueller and Schuessler 1961; Nie et al. 1975), used in 1982.

RESULTS

Initially, data interpretation was made from the CCRS 9 × 9 Kodak Aerochrome Infrared photos. This proved to be very costly and required a great deal of coordination to get the specialized aircraft and camera system when required. On the other hand, the 35 mm camera could be simply attached to a locally rented Cessna aircraft. The 35 mm slides were originally made into 8 × 10 Cibachrome prints and both the slides and prints were interpreted using a 3 + 8 power Wild-Heerbrugg mirror stereoscope. It was concluded that 35 mm CIR transparencies were equivalent to similar scale 23 cm CIR photographs for determining colour, texture and resolution. The transparencies could be evaluated for colour on a projection screen and for texture using a hand held stereoscope and simple light table. This eliminated the more expensive Cibachrome print and Wild-Heerbrugg mirror stereoscope.

This biomass estimation process was tested using five interpreters with varying amounts of experience. No significant differences were found between the five interpreters for estimating biomass. While experience was a factor, the individuals with limited and no photo interpretation experience and the interpreters unfamiliar with the vegetation and/or site were not at a significant disadvantage in estimating biomass.

Both large scales of 35 mm CIR photography (1:2,500 and 1:5,000) provided biomass estimations of equivalent accuracy in June while 1:2,500 scale provided more accurate estimation in mid-July. Biomass estimates were made to a level of precision of 20 g/m^2 or 200 kg/hectare in June and 40 g/m^2 in July. A curvilinear relationship between texture, colour and biomass was identified. It appears relatively consistent between June and July between various community pastures and between the years of the study.

SUMMARY AND CONCLUSION

The development of an operational forage evaluation system using remotely sensed data is ongoing at the Agriculture Canada Melfort Research Station, Saskatchewan. Qualitative assessment of colour and textural parameters on 23 cm format CIR aerial photography in 1979 indicated good potential for biomass estimation for parkland seeded pastures using this type of imagery. The comparability of the necessary information (colour, texture) ease of interpretation and lower cost of 35 mm in relation to 23 cm format photography warranted its initial consideration in 1981 and continued use in 1982 and 1983. During the 1981 program, six pasture types and nine biomass classes (25 g/m^2 increments) were successfully identified using colour and texture from 1:5,000 scale 35 mm CIR transparencies.

In 1982 and 1983, the program was modified to include seeded rangland pastures most representative of the parkland area of Saskatchewan. Results indicated that relatively accurate (accounting for 70-90% of the variability in the clipped biomass values) and precise (20 g/m^2 increments) biomass estimates could be made from the large scale (1:2,500 and 1:5,000) 35 mm CIR aerial photography in June. Biomass estimates made in June from the 1:2,500 scale photography were not significantly better than the corresponding 1:5,000 estimates; however, the larger scale did improve the accuracy in July. The most effective photo interpretation method developed was the 17-class texture method, wherein the interpreted texture was evaluated in 25% segments within each circular sample site. An evaluation of photo interpreter results indicated that the photo interpretation methods could be rapidly learned and easily employed to produce accurate biomass estimates, independent of interpreter qualifications.

Thus, a manual photo interpretation methodology for estimating herbage biomass using 35 mm transparencies and hand held stereoscope has been tested for selected parkland seeded pastures in Saskatchewan. Further refinement, testing, areal expansion and incorporation of Landsat data in 1983 was completed in a program involving potential user agencies, (Saskatchewan Dept. of Agriculture - Lands Branch, PFRA and Crop Insurance Board). The system was tested using test sites at Melfort, Pathlow Community Pasture and Davidson PFRA pasture. Several interpreters were able to correctly classify the photographic data into the respective biomass classes. The Landsat MSS data is presently being evaluated by Intera and the final report will be available in late June.

TABLE 1. Interpreted Texture Classes

Class No.	Class Name	Description
1	Fine	Many small points barely discernible using 8x stereo; at 1:5,000 scale no height of vegetation can be discerned.
2	Fine-Medium*	Intermediate between classes 1 and 3.
3	Medium	Small spot-like appearance discernible using 8x stereo; at 1:5,000 scale, vegetation has visible height.
4	Medium-Coarse*	Intermediate between classes 3 and 5.
5	Coarse	Relatively large spots easily discernible using 8x stereo; at 1:5,000 scale vegetation cover has definite height seen in shadowing within the canopy.

*Between the major categories are intermediate categories (fine-medium and medium-coarse), and their definitions likewise fall between those of the major categories. It was expected that texture of the forage canopy might be related to productivity and possibly to forage type. As ground cover, forage height and forage density increase, texture likewise increases along the scale from fine to coarse. This also depends, to a certain extent, on the structure and morphology of the canopy and may thus indicate forage species.

Poster Paper No. 3

SOLUTIONS TO SOME ENVIRONMENTAL AND HEALTH PROBLEMS IN THE AERIAL APPLICATION OF TOXIC CHEMICALS

Itzhak Hirsch
Operations Manager
Chimavir Services
Hertzliya Airport
Israel

INTRODUCTION

Growing cotton as a major crop in Israel's Agriculture in the last 3 decades has led to the emergence of a strong aerial application industry. Gradually, the airplane and the helicopter have evolved as vital tools in the process of agricultural crop production.

During the last decade, the quality of aerial application has increased, safety to our pilots and ground crews has improved and hazards to the environment from noise and chemical pollution have been reduced. All this is due to quieter and safer aircraft and power plants and due to better understanding of the behaviour of airborne particulates released by aircraft.

Concurrently, we have been witnessing a continuous invasion of suburbia and rural housing into agricultural territory which in turn increased public protests against noise perturbing the calm early morning hours and against the potential hazard from drift of chemicals. In spite of improvements in handling equipment and protective wear, there is a rising concern on the part of spray workers about the occupational hazards to their health.

Complaints against noise come from inhabitants near airports and airstrips from which we take off in the predawn and early hours of the day and from residents in houses situated near fields being treated from the air.

Charges against drift of chemicals have been received from many sources:

a) Residents of suburban homes adjacent to cotton fields, complaining of being poisoned following aerial spraying.

b) Residents of farming communities complaining of drifting poisons entering their homes, usually after spraying adjacent fields of neighbouring farms.

c) Accusations of mass poisoning of school children exposed to Malathion Bait sprayed on citrus orchards against Medfly (Ceratitis capitata). These occurrences took place in new schools built in the outskirts of cities close to citrus groves.

Concern of air and ground crews about their health was vehemently expressed in 1980 when they refused to handle and spray Chlordimeform (Galecron, Fundal) based on a fear that this chemical may cause malignant growths in humans. Spraying was resumed only when special precautionary self imposed procedures and monitoring of exposure were undertaken.

As a result of the loud and outspoken public outcry against noise and drift of chemicals caused by agricultural aircraft several measures have been introduced by the government and agricultural aircraft operators to solve the problems and reduce complaints.

REDUCING NOISE LEVELS

The largest operator, Chimavir Services has, since 1976, gradully changed its fleet of S2R Thrush-Commander agricultural airplanes powered by the noise generating Pratt & Whitney R-1340 radial engine, replacing this engine with turboprops. Today, the company operates 17 Turbo-Thrushes, 6 of which are powered by the Garrett Airesearch TPE-331 and 11 by the Pratt & Whitney PT-6 engines. The introduction of the quiet turbine engine has significantly reduced the noise levels.

The Airport Authority has imposed a curfew at Hertzliya Airport, home base for the aerial application companies, situated in the city of Hertzliya, north of Tel-Aviv. No take offs or landings are permitted before 06:30 h in the morning.

Flying of agricultural aircraft over populated areas has been coordinated with municipalities concerned in a manner that ensures minimal intrusion of agricultural aircraft over populated space. Special ferry routes are voluntarily being followed in order to minimize public complaint.

REDUCING COMPLAINTS AGAINST DRIFT

In 1979, the Ministry of Health issued a regulation forbidding aerial application of poisonous and harmful chemicals over dwellings or in a buffer zone of 120 metres. Exception to the rule are:

a. Spraying of Lindane and Diazinone against locust as directed by the Plant Protection Department, Ministry of Agriculture, and

b. Spraying of Staley Bait and Malathion to control Medfly in Citrus Plantations, as directed by the Citrus Marketing Board.

Following more public complaints from people exposed to spray drift of Malathion applied in Citrus for which no "buffer zone" was required, the Ministry of Health appointed a Committee to investigate whether the 120 meter wide "buffer zone" and its exemptions are adequate or should be altered. Among the subjects to be considered by the Committee are:

a. Since toxicity levels of chemicals to humans vary widely between various chemicals, it seems that the required buffer zone may be shortened for less toxic chemicals and enlarged for highly toxic materials (1).

b. The 120 metre "buffer zone" is an arbitrarily selected distance that does not consider climatological factors that will determine if and to what distance chemicals will travel downwind, contaminate the environment and endanger residents. These climatological factors are wind direction and velocity and atmospheric stability.

The Ministry of Health was criticized for completely ignoring the already established practice by operators and growers to avoid drift towards residential areas by spraying only when the wind is blowing from the residential area towards the field treated. It was suggested (2) that special permits to spray within the buffer zone be issued on condition that spraying take place only when a minimum positive air movement of 2 knots from the dwellings towards the spraying area exists before and during spraying operations. On the other hand, the width of the buffer zone should be increased in "no-wind" conditions or when wind direction is from the treated fields towards the residential area.

In fact, there are many examples of neighbourly understandings between the aircraft operator, the grower and the residents of nearby homes in which the parties concerned confer and mutually agree on ways and means to carry out aerial application only at times when wind direction and velocity assure that no drift will reach the housing area.

FRIENDLY HELICOPTERS

It is worthwhile to note that replacing fixed wing airplanes with helicopters in areas where public concern about noise or drift is increasing, has greatly reduced the frequency and extent of complaints.

DISPOSAL OF CHEMICAL WASTES

Agricultural aircraft land at the end of each day's work at regional airstrips where they are decontaminated and cleaned. To avoid leaching of poisonous chemicals into the ground and contaminating the aquifer beneath, chemical wastes are collected and channelled into open, water-tight, evaporation ponds. Due to direct solar radiation, water evaporates and the chemical waste is biodegraded and dried out.

PILOT FATIGUE

Aerial application of toxic chemicals takes place mainly during the hot and dry summer, when large areas must be treated in a short time. A survey in Israel on agricultural pilots by Baruch (3) found that flying in hot and dry weather caused significant impacts on the pilots including: loss of weight, decrease of blood sugar level, decrease of eosinophil cells and increase of body temperature. Consequently regulations limiting flying and duty time for agricultural pilots have been reissued as shown in table 1. The distinction between classes of outside temperature seems inappropriate for pilots flying in fully airconditioned airplanes.

In his study, Baruch found no exposure to cholinesterase inhibiting chemicals for pilots working with these materials. However, Pardo (4), when testing air samples in cockpits of airplanes and helicopters, found varying concentrations of Parathion and Dursban, although all were below the Threshold Limit Values (TLV). On the other hand, Gordon and his associates (5), checking cockpit air exposure levels for short periods (11-21 minutes), found the Parathion concentration to exceed the TLV in 8 out of 14 instances. It would be worthwhile to continue research on cockpit exposure especially since pilots of one company have been complaining about what appears to be an increased concentration of toxic chemicals in the cockpit when spraying with a fine drop spectrum used for cotton since 1981.

SPAYING PROCEDURE AND FLAGGING

The argument as to what extent spraying of fields using the "Round Robin" procedure reduces cockpit exposure to chemicals as compared to the "back and forth" procedure, has not yet been settled. Pilots prefer the Round Robin type of application, which is used for cotton spraying since the fields are marked by colored and numbered plastic boards in lieu of flagmen. In addition to solving the problem of flagmen exposure to pesticides, flagging by boards makes the pilot independent in choosing where to begin spraying a field. The pilot then uses his own experience and judgement to steer his craft out of the drifting cloud of chemicals. Results from 4 years of urine tests to monitored exposure to Chlordimeform have shown pilot exposure to this chemical was close to zero. By a self imposed rule, all applications with Chlordimeform were carried out using the "Round Robin" pattern at minimum wind speeds of 2 knots.

MONITORING EXPOSURE TO PESTICIDES

Measuring exposure of pilots and ground crew to cholinesterase inhibiting pesticides by determining cholinesterase levels in venuous and finger-prick blood samples is still used routinely. However electromyography (EMG) testing of spray workers has been carried out experimentally at hospitals (6) and in the field (7) and may be a more sensitive indication of the cumulative neurotoxic effect of low exposures to Parathion. For the moment EMG testing is still in the investigative stage and cannot replace cholinesterase tests.

A program for finding a better method to measure exposure to Organo-Phosphorous pesticides than cholinesterase assay was initiated by Levy (8). He aimed at determining urinary alkyl phosphate to replace cholinesterase tests. Finding a reliable urine test to measure exposure to organo-phosphates will facilitate tremendously the whole process of sampling transportation and analysis. As has been shown during four years of urinary tests to determine exposure to chlordimeform, collecting of urinary specimens is simple, painless and easier to handle than collecting and handling of blood samples.

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TABLE 1. Flying Time and Duty Time Limitations in Hours, For Agricultural Pilots

	24 Hr	Weekly	Monthly	Quarterly	Yearly
Actual Aerial Application	4* 6	30	80	200	600
Total including Ferry Flight	5* 8	40	100	250	800
Duty Time	8* 10	-	-	-	-

*Lower figures are for work with toxic chemicals and at outside air temperatures between 32° to 36° Centigrade. Aerial application at temperatures above 36°C is prohibited.

Poster Paper No. 4

FIELD METHOD OF ASSESSING AIRCRAFT SPRAY WIDTHS

A. Lavers
Shell Research Ltd.
Sittingbourne Research Centre
Sittingbourne, Kent
U.K.

INTRODUCTION

For correct calibration of the spray output per given target area for an agricultural spray aircraft, it is necessary initially to ascertain the effective spray swath width (lane separation). Unlike terrestrial-based application techniques, where swath widths can easily be calculated, spray released into the wake of the aircraft is subject to many complex forces that can influence droplet trajectory and sedimentation. While crop morphology, pest ambit and metereological conditions cannot be influenced directly, some control over applied volume, formulation, and droplet size can be exerted in order to improve the overall spray efficiency.

Methods of measuring aircraft swath width vary, not only in accuracy, but also in the time required to produce meaningful results. These results are dependent upon the field equipment used and the skill of the technicians using it. Two methods are commonly recommended: firstly, an assessment of numbers of droplet stains on artificial or natural surfaces (droplets/cm^2) and, secondly, volumetric analysis, where the volume recovery per given area is calculated (litres/hectare - gal/acre). Volumetric analysis by colorimetry or fluorimetry has previously required laboratory back-up, but recently portable field equipment has been developed that can quickly produce results.

This presentation will concentrate on swath width estimation in the field by droplet stain analysis obtained from a single aircraft flight.

OBJECTIVE

As an initial guide, the effective liquid spray swath width for an aircraft using boom and nozzles to apply conventional volumes (20 litres/hectare) is taken at 1.5 times the aircraft swing span, or lower wing span when referring to a biplane.

However, when an aircraft is spraying at ultra-low volume (ULV) rates, i.e. <5 litres/hectare, flying height and subsequently swath width are increased. This presentation uses droplet recoveries from both fixed and rotary wing aircraft to determine effective spray swath width. Although the droplet recovery number obtained from an artificial target does not always correspond to the degree of biological control achieved in the field, the use of artificial targets can act as a guide in determining the aircraft swath width and subsequent lane separation in the field.

METHODS AND MATERIALS

Swath width determination is obtained from a single aircraft flight when the aircraft is flying into the wind. The aircraft flies at spray height over a line of artificial targets (water-sensitive paper) placed 1 metre apart at right angles to the flight path. The sampling line extends four times the aircraft wing span or helicopter rotor span and the artificial targets are clipped to stands 300 mm above ground level. To compare droplet number recovery with volume recovery (Fig. 1), droplets caught on magnesium oxide coated slides were removed to the laboratory and measured on an image analyser.

It must be emphasized that droplet recovery from artificial targets can only be used as a general guide. The interception of droplets by insects or plant surfaces is achieved by sedimentation and impaction, impaction being particularly important for aerosol droplets (<60 micrometres diameter), which are not usually collected by stationary artificial surfaces. Variations in target surface influences the turbulence of the air flow over the surface and subsequently the droplet recovery. Accordingly, it is recommended that natural surfaces should, where possible, be used for spray recovery assessment. Under field conditions, where a quick result is required, the use of artificial targets is acceptable.

Although difficult to assess, the rubber test foils offer the operator a quick method of checking spray cover on the target. Magnesium oxide coated glass slides, 25 × 75 mm, can be used for droplet size assessment. Droplets impacting the magnesium coating leave a clear crater, which can be measured with a pre-calibrated graticule, or by image analysis. Coated rigid paper changes colour after collecting aqueous droplets, but drop definition can be reduced when the relative humidity is high and the sensitivity of the coating is affected. Photographic paper gives clear droplet definition but must be exposed for only a limited time. Finally, the encapsulated paper can be used to assess the deposition from an application of an oil-based spray (ULV), when the droplets dissolve the wax surface to produce a black stain on a white background.

It is inadvisable to determine droplet size from stains on artificial targets unless the droplet spread factor has previously been established in the laboratory using a similar formulation and dilution rate to those monitored in the field.

Droplets per square centimetre are counted using a hand lens and are then plotted on a graph to determine the overall spray pattern and the droplet numbers.

CASE STUDIES

Table 2 lists five case studies, two conventional applications at 20 and 30 l/ha and three ULV applications, including one ULV application achieved with a boom and nozzle assembly (3). The resulting droplet counts can be found in Figures 1 to 5.

RESULTS

Figure 1 shows a comparison between the droplet count and applied volume recovery obtained by sizing droplets collected on magnesium oxide coated glass slides. The effect of the propeller in redistributing the spray from port to starboard is clearly illustrated. The glass slides were positioned on the same stands as the water sensitive paper for this evaluation, where the volume recovery gave a similar profile to the droplet number recovery.

Figure 2 shows a typical recovery from a small aircraft fitted with four Micronair Au 3000 rotary atomisers. Deposition peaks, usually due to inadequate flying height, are reduced by the cross wind component under field conditions. Figure 2 clearly indicates the effect of propeller and fuselage 'screw' redistributing spray from the port side to the starboard side. Although the spray uneveness can be corrected by adjusting nozzle positions, aircraft fitted with rotary atomisers have limited spray emission points, so the flying height during application has to be increased in order to allow the spray clouds to develop fully.

Figure 3 records droplet numbers from a low winged aircraft spraying at ULV rates with boom and nozzles. Droplet numbers from this application gave inadequate target cover of a contact insecticide, resulting in unacceptable control of maize stalk-borer (Busseola fusca). The wide droplet spectra from the hydraulic nozzle used for the application (volume median diameter 330 micrometers) produced a poor spray distribution, with 30% of the droplets in the size range not collected by the artificial target at the assessment. The droplet recovery proved inadequate for a ULV application of insecticide.

Figure 4 shows the droplet recovery from an aircraft applying 2 l/ha to pine trees to control the larval stages of Lymantria monacha. The droplet numbers recovered proved low, influenced by the low count in the centre of the swath where the gap between the inboard atomisers, coupled with the reduced liquid flow from the variable restrictor unit, reduced the application rate, and therefore droplet recovery.

Figure 5 was obtained from a Thrush aircraft fitted with ten Micronair Au 5000 atomisers. The increased number of spray emission points, five per wing, reduced the pronounced peaks in the spray pattern often observed when the aircraft flies too low over the target spraying at ULV rates using rotary atomisers.

CONCLUSIONS

It is difficult to estimate exact swath widths for individual aircraft, but figures 1-5 illustrate certain swath widths are too wide. As a guide, the swath cut-off can be taken where the recovery does not reach the median number. Although, under field conditions the repeatable swath width may be wider when a cross wind is present. Asessing spray droplet stains on artificial targets provides a practical method for checking the swath width, spray distribution and nozzle configuration. Droplet counting was validated by volumetric recovery assessment, but methodology proved time consuming and expensive, without giving an immediate result.

The spray recovery efficiency is influenced by such aircraft design factors as the position of the engine exhaust emission, or the degrees of flap maintained during flight, but similar aircraft must not be assumed to give identical spray recoveries.

Determining the effective swath width, and subsequent field lane separation, will lead to efficient aircraft and pesticide use, and Table 3 gives a median guide to the droplet numbers required for acceptable control.

TABLE 1: Artificial Target Papers

Target Type	Sensitivity
Rubber test foils	Wettable powders and suspension concentrates
Magnesium coated glass slides	Aqueous suspensions and oil based formulations
Coated rigid paper	Aqueous suspensions
Photographic paper (unexposed)	Aqueous suspensions
Encapsulated paper (oil sensitive)	Oil-based ULV formulations

TABLE 2. Case Studies - Aircraft Application Details (Flying Into The Wind)

Aircraft type	Applied Volume 1/ha	Estimated swath width m	Corrected swath width m	Air speed km/h	Nozzle/atomiser detail
1. Mikhail Mi2 helicopter (Iraq)	30.0	40	28	100	132,2 mm cone jets working at 300 kPa
2. Cessna Agtruk (Sudan)	2.0	30	25	160	4 Micronair Au 3000 atomisers Blade angle 35° Variable restrictor units - 9
3. Pawnee Brave (S. Africa)	2.8	25	21	180	32 fan jets (80015) working at 280 kPa
4. Antanov AN2 (Poland)	2.0	40	30	160	6 Micronair Au 3000 atomisers Blade angle 35° Variable restrictor units - (a) Inboard 2-7 (b) Outboard 4-9
5. Ayres Thrush (Sudan)	20.0	30	30	170	10 Micronair Au 5000 atomisers Blade angle 35° Variable restrictor units - 13 Working pressure 200 kPa

TABLE 3: A Guide to Droplet Numbers for Different Treatments

Treatment	Droplets/cm^2
Insecticides	25
Herbicides (foliar applied)	40
Fungicides	55

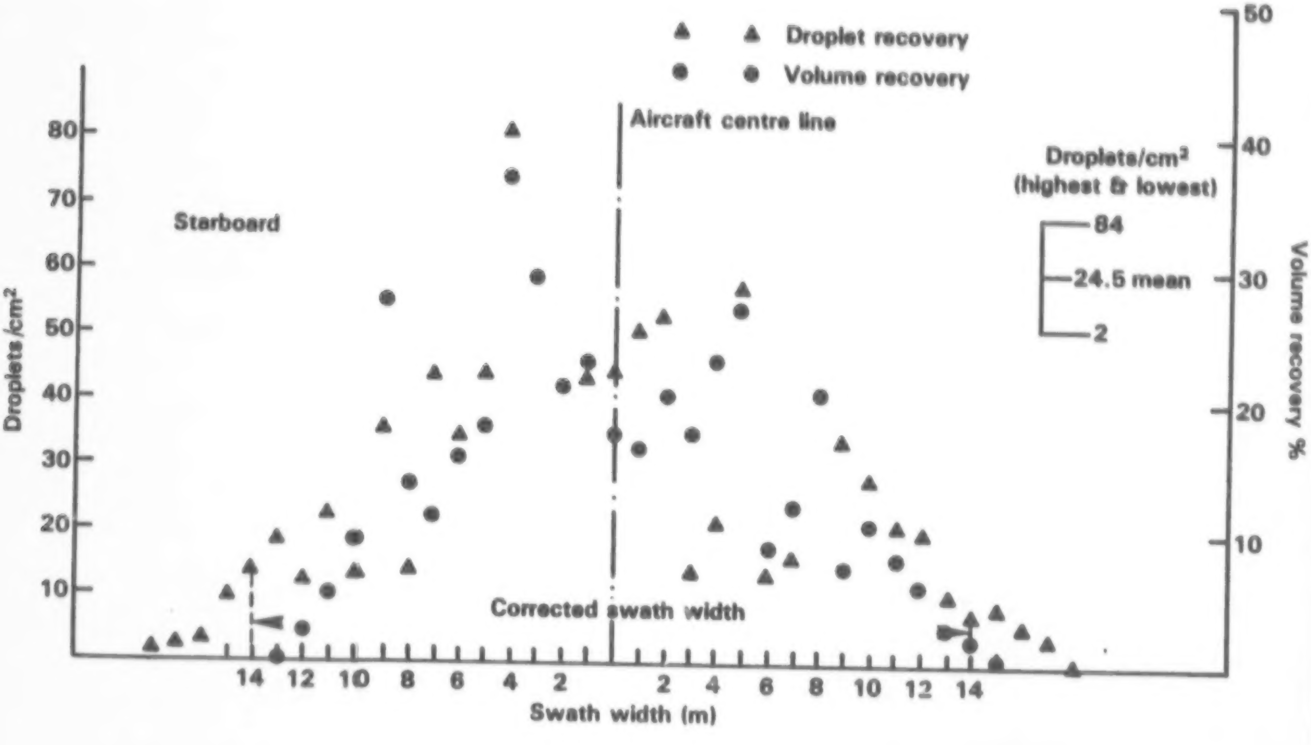

Figure 1. Droplet recovery from a Mikhail Mi2 helicopter fitted with 130 2mm cone jets. (30 l/ha).

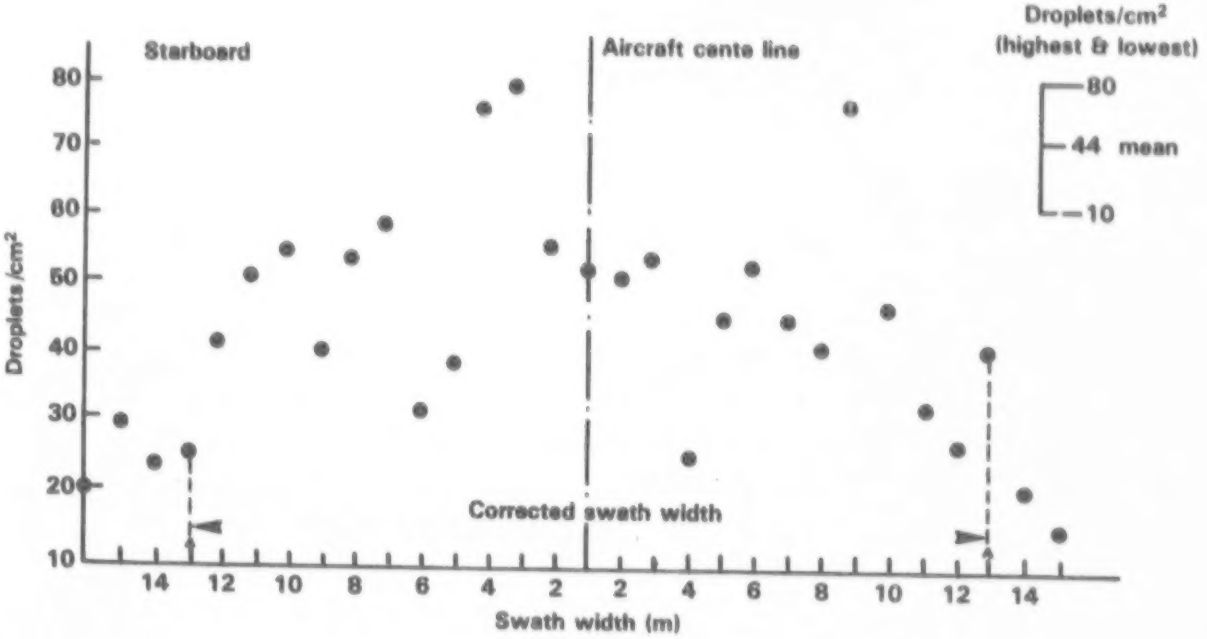

Figure 2. Droplet recover for a Cessna Agtruk fitted with four Micronair AU 3000 atomisers (2 l/ha).

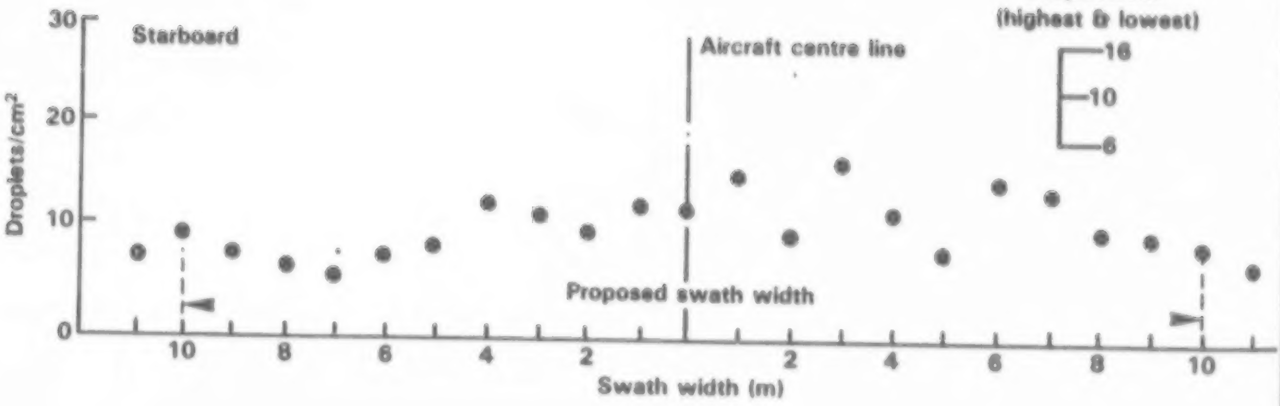

Figure 3. Droplet recovery from a Pawnee Brave 375 fitted with 32 80015 fan jets (2.7 l/ha).

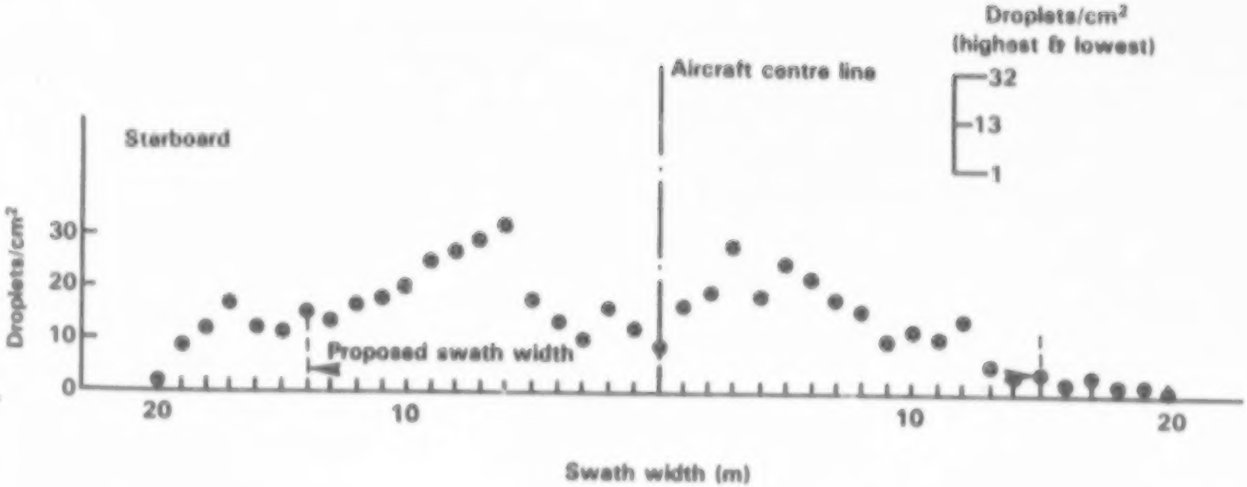

Figure 4. Droplet recover from an Antano AN2 fitted with 6 Micronair AU 3000 (2 l/ha).

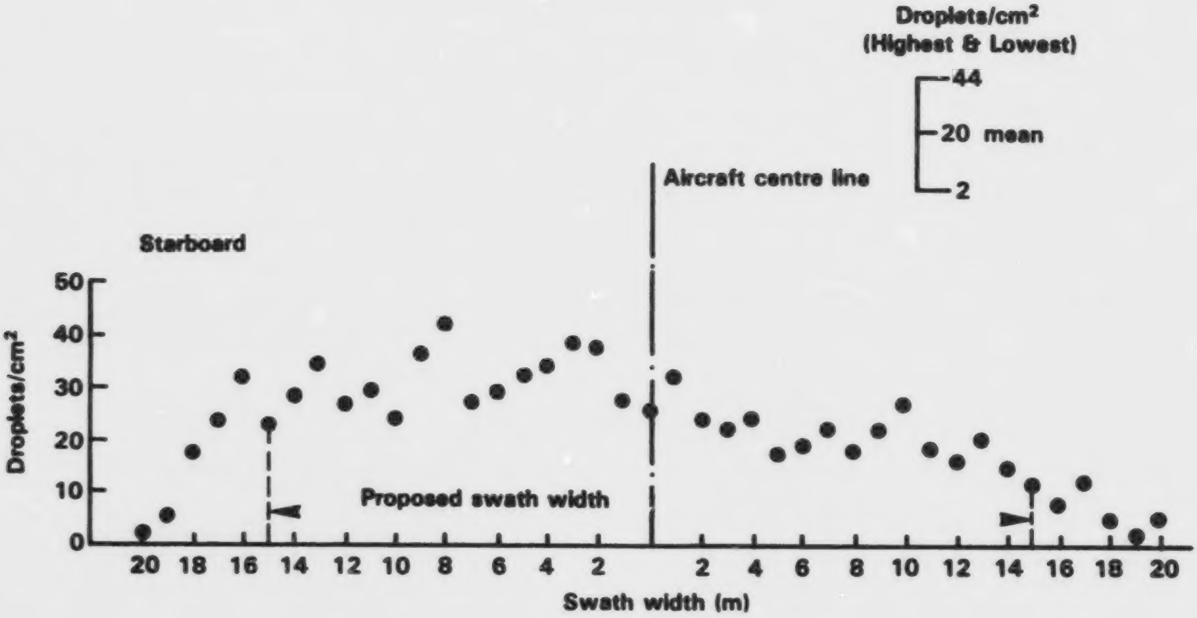

Figure 5. Droplet recovery from a Thrush aircraft fitted with 10 Micronair AU 5000 (20 l/ha).

Poster Paper No. 5

LAGRANGIAN SIMULATION OF FOREST PESTICIDE SPRAY DISPERSION AND DEPOSITION

N. Basak and J.J.C. Picot
University of New Brunswick
Department of Chemical Engineering
Post Office Box 4400
Fredericton, N.B.
E3B 5A3

ABSTRACT

A Monte Carlo technique using Lagrangian trajectory calculation for the motion of suspended droplets in the atmosphere was used to calculate aerial spray droplet dispersion in the atmosphere and subsequent deposition on foliage and the ground. The model incorporates the effects of droplet emission spectrum characteristics, droplet evaporation, atmospheric wind profiles and turbulence, forest stand characteristics, and droplet impaction on needles as well as droplet settling. The very important aircraft vortex effect is treated empirically. The computer program computes droplet drift, droplet deposit on the canopy, and droplet deposit on the ground as a function of time and position. Program predictions are compared with field trial results conducted near Dunphy airstrip in New Brunswick in 1982 and 1983. Agreement is good provided that the "effective droplet release height" is properly chosen. The results show the primary importance of the aircraft vortex effect and also that of droplet spectrum and weather conditions in controlling spray efficacy and off-target drift.

INTRODUCTION

The Lagrangian technique can be used to calculate the trajectories of aerial spray droplets. The computer model calculates droplet deposition on the foliage canopy and ground as well as concentration in the air as affected by atmospheric convection and turbulence, gravitational settling, evaporation, type and density of trees and foliage and physical properties of the chemicals used. Aircraft vortex effects are considered to a certain extent. Therefore, this program enables the user to get information on the effectiveness of aerial spraying of forested areas as a function of time and downwind distance.

Foliage deposition is treated as an inertial impaction problem with the needle diameter as the characteristic dimension. Needle area density per unit area of ground is obtained from correlations valid for local species.

If the program adequately simulates experimental trials, new data can be obtained without the effort of actual experimental trials for all cases. With the data generated by the program, the optimum droplet diameter can be determined. The combination of parameters that give the desired results can also be determined. Parameters that are not available experimentally, (e.g. Lagrangian timescales) can be predicted from correlations in the literature.

Data from field trials in Dunphy, N.B. in 1982 and 1983 were used to test the validity of the numerical results.

THEORY

Atmospheric dispersion of spray droplets is caused by wind convection and turbulence. Most of the droplets are small enough and they drift following the air flow. Therefore, the problem of calculating atmospheric dispersion of the spray droplets can be viewed as that of calculating their trajectories from knowledge of convection and statistics of turbulence.

The atmospheric boundary layer is marked by inhomogeneity of turbulence. This means that the statistical properties depend on location, i.e. as a fluid element moves farther from the ground, it encounters motions of increasing persistence (time scale) and of changing intensity (velocity scale). This inhomogeneity is especially important in the vertical direction as a result of wind shear and stability. The magnitude of the fluctuating velocity component increases with height, as does mean horizontal wind velocity.

The Lagrangian approac[illegible]s most appropriate for trajectory calculations. This approach is concerned with the behaviour of representative fluid particles, and particle concentration changes are described by following the motion of the carrier fluid (7).

We begin by considering a single particle at a location x at time t in a turbulent fluid. The subsequent motion of the particle can be described by its trajectory, i.e. its position at a later time.

There is a correlation between the fluctuating velocities at time t and a later t + Δt. The fluid has a decaying memory for its previous velocity. These random fluctuating velocities cannot persist throughout a large timestep Δt.

As Δt is made smaller the correlation coefficient approaches unity. For a large Δt, the fluctuating velocity at t does not have any effect on the velocity at t + Δt, hence the correlation between them is zero.

The basic parameter of the statistical theory is the Lagrangian time scale of turbulence, which can be defined as the persistence of the motion. Mathematically, it is the time integral of the Lagrangian autocorrelation function.

$$R_L = \frac{\overline{u'(t|z)u'(t+\Delta t|z)}}{\bar{u}'^{z}}$$

and

$$\tau_L(z) = \int_0^\infty R_L(z,\xi)d\xi$$

where $\xi = \Delta t$ and $u'(t|z)$ is the instantaneous velocity at time t of a fluid element which was at height z when released.

Since velocities cannot persist throughout a large timestep, it is convenient to choose the timestep Δt as 10% of the Lagrangian timescale as suggested by Wilson (7) to follow the droplets accurately.

$$\Delta t = 0.1\ \tau_L(z)$$

The autocorrelation function R_L can be approximated by an exponential expression if Δt is sufficiently small:

$$R_L = \exp(-\Delta t/\tau_L)$$

The only problem with the Lagrangian theory is to accurately determine the particle statistics. The Lagrangian timescale is difficult to measure directly. However, there are approximate theories that assume relationships between Lagrangian scales and readily measured Eulerian scales of turbulence.

The Eulerian characteristics of surface layer turbulent flow are characterized by u*, the friction velocity. We can assume that Lagrangian statistical properties of the surface layer are also governed by u*.

The computer program uses 4000 droplets which is the minimum number that gives adequate representation of the droplet trajectories. Three different stability classes (i.e. neutral, stable and unstable atmosphere) are analyzed. For each class, the relations used to calculate the Lagrangian timescale, velocity scale and atmospheric wind profiles are given by Wilson (9).

Timescales:

for a neutral atmosphere: $\tau_L(z) = \frac{0.5z}{\sigma_w}$

for a stable atmosphere: $\tau_L(z) = \frac{0.5z}{\sigma_w} (1+5 \frac{z}{L})^{-1}$

for an unstable atmosphere: $\tau_L(z) = \frac{0.5z}{\sigma_w} (1-6 \frac{z}{L})^{\frac{1}{4}}$

Vertical velocity scales:

for neutral and stable atmospheres: $\sigma_w = 1.25\ u^*$

for an unstable atmosphere: $\sigma_w = 1.25\ u^* (1-4.1 \frac{z}{L})^{1/3}$

Horizontal wind velocities:

for a neutral atmosphere: $u(z) = \frac{u^*}{k} \ln \frac{z-d}{z_o}$

for a stable atmosphere: $u(z) = \frac{u^*}{k} \left[\ln \frac{z}{z_o} + \frac{4.7}{L} (z-z_o)\right]$

for an unstable atmosphere: $u(z) = \int \frac{du}{dz},\ \frac{du}{dz} = \frac{u^*}{kz} (1-16 \frac{z}{L})^{-\frac{1}{4}}$

In the above equations:

L = Monin-Obukhov length = $\frac{-\rho\ C_p\ T_o\ u^{*3}}{KgH}$

z_o = roughness height (1.44 m for Dunphy 83 (3))

d = displacement height (11.25 m for Dunphy 83 (3))

k = velocity profile constant (0.4)

K = thermal conductivity of atmosphere

H = vertical heat flux in the atmosphere

The expressions for wind velocity are valid above the mean tree height. To calculate the wind velocity below the mean tree height the expression given by Belot et al. (1) is used:

$$u(z) = u(TRHT)\ \exp\left[-\alpha(1-z/TRHT)\right]$$

where TRHT is the mean tree height (15 m) and α is an experimentally determined constant that has different values depending on atmospheric stability.

Below the base of the foliage crown, $u(z)$ is taken as a constant, i.e. $u(z) = u(BCROWN)$ for $z < BCROWN$ where $BCROWN$ = base of the foliage crown, (7.5 m).

Some of the above correlations for Lagrangian time and velocity scales do not seem to fit the experimental data from the field trials adequately. For those cases other correlations were obtained by curvefitting the available experimental values.

For the trajectory calculation, we consider a two dimensional system where the Eulerian horizontal velocity is steady and depends only on the height z above the ground.

The droplet trajectory consists of a series of "jumps" with horizontal and vertical components calculated for each timestep (i.e. 10% of the Lagrangian time-scale). Each of 4000 droplets is "followed" for a time interval of 10 seconds. The program locates all droplets at the end of the time interval, and the whole operation is repeated until a total elapsed time of 400 seconds has been reached. For each jump, the components are calculated as follows:

$$x = x + \Delta x\ ;\ \Delta x = u(z)\Delta t$$

$$z = z + \Delta t\ ;\ \Delta z = W(z)\Delta t$$

where $W(z) = W_L(t) + W_L + W_g$

and

$$W_L(t) = W_L(t-\Delta t)\exp(-\Delta t/\tau_L) + \{1-\exp(-2\Delta t/\tau_L)\}^{\frac{1}{2}}\,\sigma_W \cdot r(t)$$

$W_L = \tau_L \dfrac{\partial(\sigma_W^2)}{\partial z}$ (bias velocity)

W_g = terminal settling velocity of droplet

$r(t)$ = random number from generator with mean zero and standard deviation of unity.

The W_L term is called "bias velocity" and is required since an increase of σ_W with height implies that there is a net downward flux of air in the atmosphere, an unrealistic situation. The above choice of formulation therefore biases the net downward mass flux to zero for the air.

The droplets have a gravitational settling velocity because they are heavier than the surrounding air. The terminal settling velocity depends on the Reynolds number, the instantaneous droplet diameter, density and viscosity. The instantaneous droplet diameter is always less than the initial droplet diameter due to evaporation.

In the Stoke's law region, $Re < 0.3$;

$V_s = 9.8D^2 \dfrac{(\rho_L - \rho_A)}{\mu_A}$ (the subscript A stands for air)

If $0.3 < Re < 1000$; $V_s = \left[\dfrac{513\ D^{1.6}}{\rho_A^{0.4}}(\rho_D - \rho_A)\right]^{1.429}$ is used (4).

For the evaporation of the droplets, the change in diameter is taken into account using the relation given by Picot et al. (6)

$$\frac{dD}{dt} = -\frac{2M_V\, D_V\, \rho_A}{M_m\, D_t\, \rho_L}\,\frac{\Delta P}{P_f}\left[2+0.6\ Re^{\frac{1}{2}}\ Sc^{1/3}\right]$$

where:

D = droplet diameter

M_v = molecular weight of evaporating vapor

M_m = molecular weight of resulting vapor air mixture

D_v = molecular diffusivity of evaporating vapor in air

ρ_A, ρ_L = density of air and liquid in droplets respectively

ΔP = vapour pressure of evaporating liquid at droplet surface minus vapor pressure in ambient air.

P_f = air partial pressure

Sc = Schmidt number = $\mu_A / D_V \rho_A$

The droplets evaporate until their final diameter reaches 53% of their initial diameter because they contain 85% of water by volume.

If a droplet's vertical location z at the end of a jump is 2m or below, ground deposition takes place due to very low wind velocities at these heights.

The probability that a droplet will deposit on the canopy depends on a number of factors:

probability = impaction efficiency × path travelled by droplet × foliage interception factor × needle orientation factor

where:

$$\text{foliage interception factor} = \frac{\text{cross sectional area of foliage}}{\text{cross section of window over whole path length}}$$

The needle orientation factor refers to the probability that needles are oriented with their greatest projected area normal to air flow.

The impaction efficiency is calculated based on a modified version of the empirical May and Clifford correlation. The May and Clifford correlation (2) is modified according to the results of the Kristmanson, Picot, Henderson study of impaction efficiency of needles in a "shoot" configuration (10). The impaction efficiency is a strong function of the wind velocity, hence the probability of deposition on canopy is very low at low levels.

In the computer program, the actual calculations are performed in a transformed coordinate system defined by Wilson (7) to convert inhomogeneous turbulence to homogeneous turbulence. After the new location of a droplet is calculated in this system, it is back transformed to the real z-t system. These transformations are applied for convenience and ease of calculation.

PRESENTATION AND DISCUSSION OF RESULTS

The available experimental results (3) are in the form of percentage mass on the ground and canopy, and drift beyond 400 m. The mass of emulsifiable concentrate per square meter deposited on the ground and canopy is also available. It is noted that there is a closure problem in these results. For the neutral case the three percentages add up to less than 100%, for the stable case, percent canopy deposit is not available and for the unstable case the sum is larger than 100% (see Table 1).

Table 1. (3)

	Experimental Percentages		
	neutral	stable	unstable
drift > 400 m	5	50	43.5
canopy (0 → 400 m)	70	N/A	87
ground (0 → 400 m)	9	23	11
TOTAL	84		131

The result for canopy deposition are in some error due to non-representative sampling of canopy samples. Higher impaction efficiencies occur at the treetop than further down, a factor not precisely taken into account.

Model predictions are carried out for the above experimental runs using measured values of u*, L, and turbulence statistics taken from (3). Repeated computer runs were done at different droplet sizes and the results for these runs were then consolidated using weighting factors which depend on the emission characteristics of the TEEJET 11010 nozzles actually used on the spray aircraft. These emission characteristics were measured in a wind tunnel using laser spectroscopy and flash photography. The lack of an accurate vortex model requires an estimate of the effective height at which droplets are released from the aircraft vortex. This is taken here as uniform for all runs, which is an oversimplification. Droplets were assumed to be released in a uniform density cloud in the vertical zone between 10 and 15 meters above ground. Table 2 shows a comparison between theoretical model predictions and experimental results for per cent of active ingredient drifting beyond 400 meters from the spray line.

Table 2

Drift	Neutral	Stable	Unstable
Experimental	5	50	43.5
Theoretical	56.8	14.3	24.2

These results do not seem to agree well, however it is possible to account for the discrepancy. A model for the vortex effect is not available. The vortex effect is considered to some extent by assuming that the spray droplets are released in a height range rather than at a fixed constant level and the levels chosen for the model are below the actual release height.

The contradictory prediction with respect to the difference between the effect of neutral and stable atmospheric conditions is very likely due to the differences in vortex behaviour. For the strongly stable case, the vortex tends to be suspended by buoyancy effects, while in the neutral case, no such effect is present. This was not acounted for in the theoretical calculation due to the lack of a detailed vortex behaviour model.

Figures 1 to 6 show comparisons of theoretical and experimental data for ground and canopy deposits. Agreement is acceptable in some cases.

CONCLUSIONS

The computational scheme described shows definite promise for predicting off-target drift, and canopy and ground deposit. However, a vortex wake behaviour model must be added to the system to make it complete. This additional work has been initiated.

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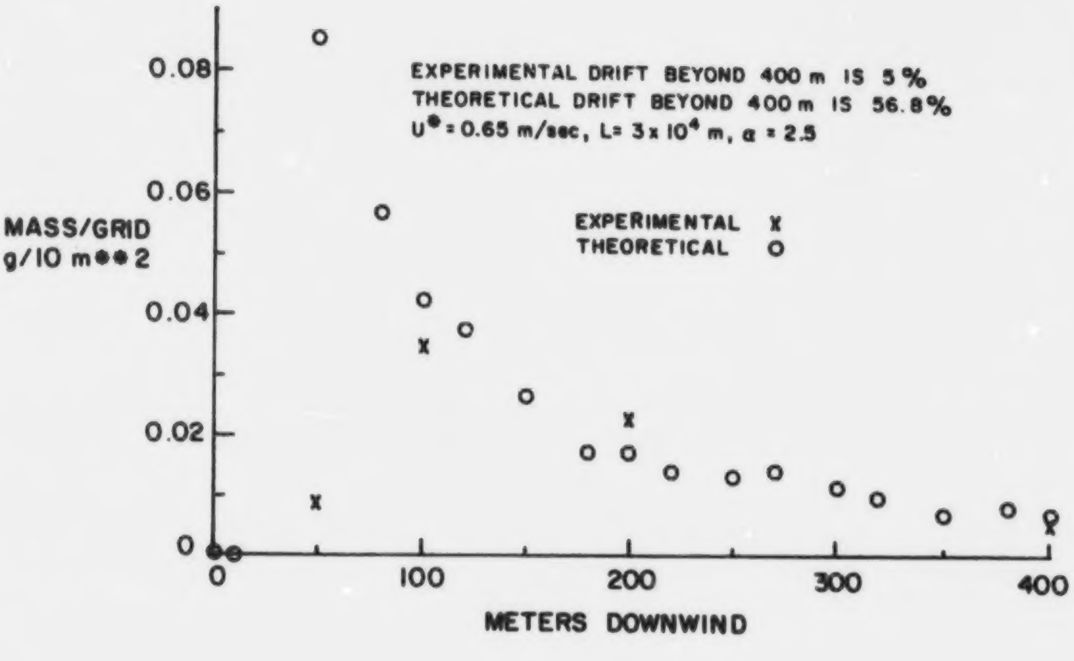

Figure 1. Canopy Deposition at x vs. Downwind Distance for the Neutral Case 27 June 1983.

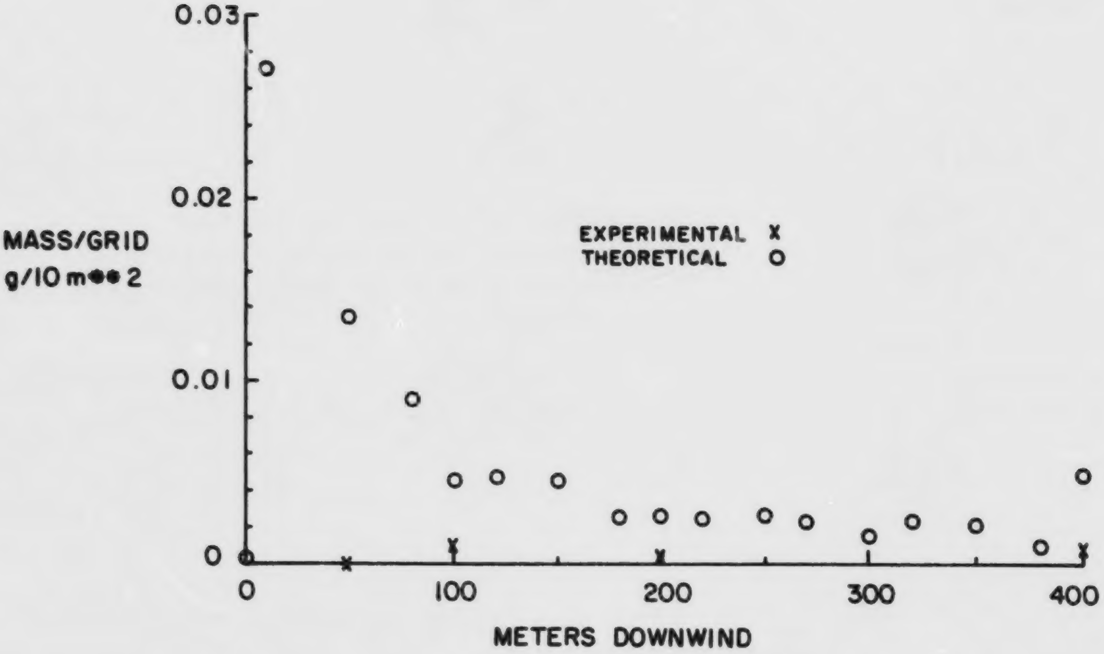

Figure 2. Ground Deposition at x vs. Down wind Distance for the Neutral Case 27 June 1983.

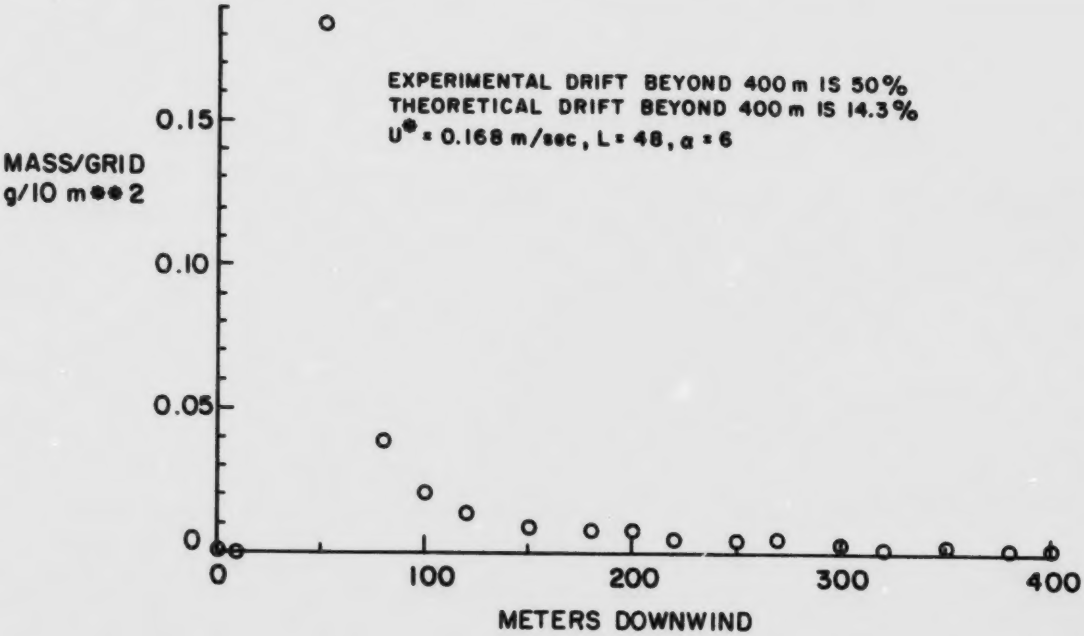

Figure 3. Canopy Deposition at x vs. Downwind Distance for the Stable Case 29 June 1983.

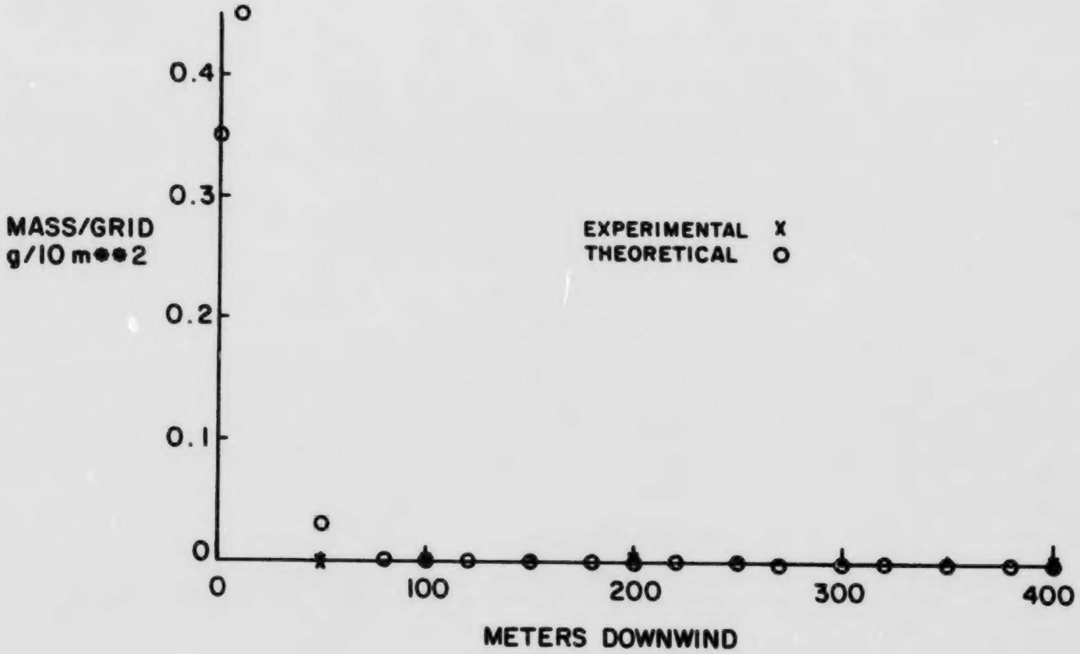

Figure 4. Ground Deposition at x vs. Downwind Distance for the Stable Case 29 June 1983.

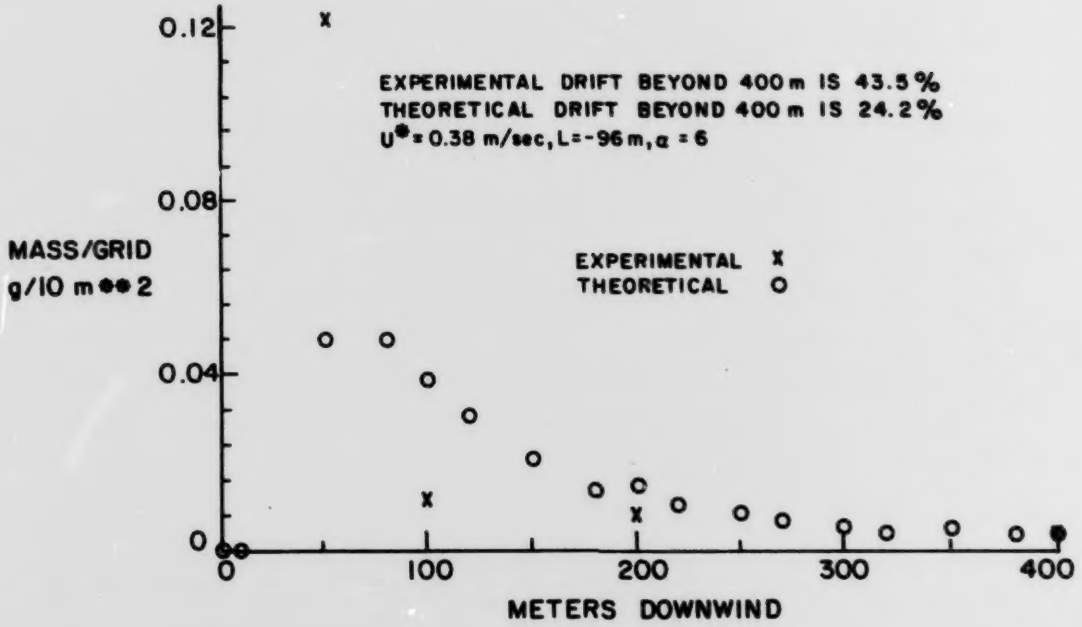

Figure 5. Canopy Deposition at x vs. Downwind Distance for the Unstable Case 22 June 1983.

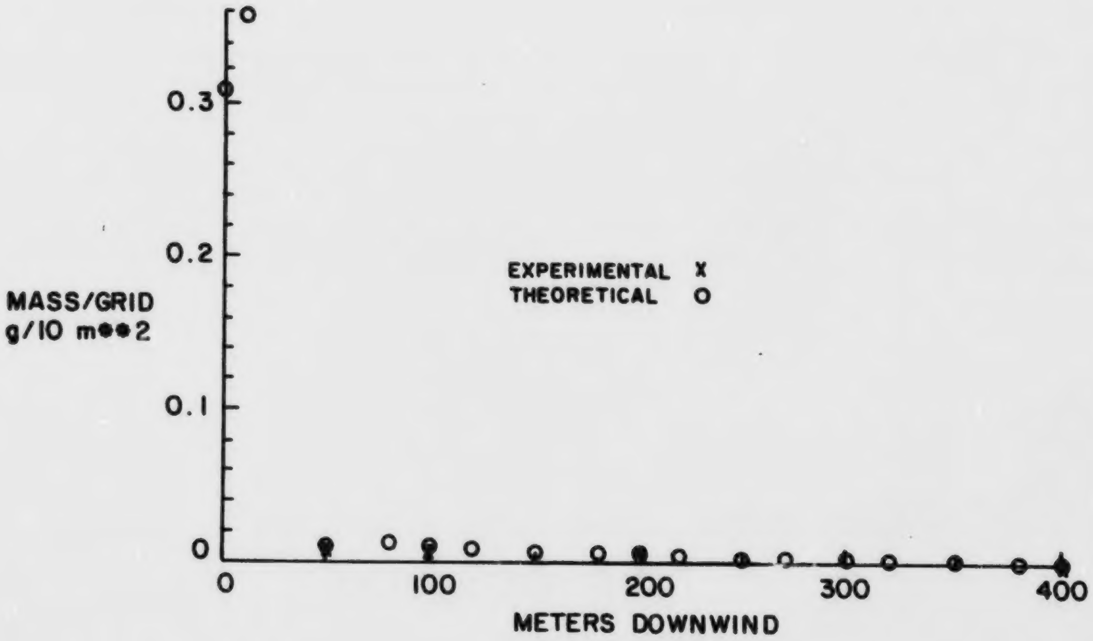

Figure 6. Ground Deposition at x vs. Downwind Distance for the Unstable Case 22 June 1983.

Poster Paper No. 6

DROPLET SPECTRUM MEASUREMENTS BY LASER PROBE METHODS

J.J.C. Picot, X. Bontemps, D.D. Kristmanson
Department of Chemical Engineering
University of New Brunswick
P.O. Box 4400
Fredericton, N.B.
E3B 5A3

ABSTRACT

Sprayer characterization was done in the NRC wind tunnel with the laser probes being traversed through the droplet plume about 1.5 m downwind of the atomizer. The light scattering results up to 55 microns were incorporated with previous flash micrography results where necessary, in view of the errors inherent in the droplet imaging probe. For a TEEJET 11010 nozzle at 3.8 l/min (water) at 67 m/s air velocity, 34% of the droplets were between 30 and 100 microns in diameter by volume. In the case of the MICRONAIR AU 3000 (11.4 l/min of water, 13.5 inch blades at 25°, air velocity 47 m/s), 73% of the droplet volume was in the 30 to 100 micron size range. The BEECOMIST 360 with a 40 micron sleeve at 13 volts D.C. in air moving at 40 m/s with 1.2 l/min of water produced 97% of its spray volume between 15 and 50 microns in diameter. Other operational parameters were investigated.

INTRODUCTION

A laser light scattering probe and a laser droplet imaging probe were used to measure the droplet emission spectrum of various commercial aerial spray atomizers. The light scattering probe (a PMS FSSP probe) was recalibrated using glass beads and the Mie equations were solved to provide calibration curves for a range of refractive index and light absorbance (1). The range of droplet size measurable with this device is from 0.5 to 55 µm. The light imaging probe (PMS OAP-260X) has a nominal range of 20 to 600 µm, and functions by projecting the shadow of the droplet onto a strip of discrete photodiodes which are read and the digital data converted to droplet diameter. Figure 1 shows the two probes and the data processing system (PMS 300). The manufacturer is Particle Measuring Systems of Boulder, Colorado.

EXPERIMENTAL

Measurements were done in the NRC 10×20 ft wind tunnel in Ottawa. The tunnel has a 40-foot long test section which was equipped with a venturi-type flow restrictor to increase its maximum speed to 170 mph (76 $m \cdot s^{-1}$). This permitted measuring atomizer characteristics at actual aircraft operational speeds. The probes were mounted so that the sampled volumes were approximately 1.5 m downstream of the atomizer. A traversing system was used (Figure 2) to permit detailed analysis over the full cross-section of the spray plume. The tunnel air flow was laminar in all cases. Droplet evaporation was negligible for droplet sizes down to 10 µm for volatile formulations (in this case, water or methanol-water solutions), but were probably significant at smaller sizes. Measurements done much closer to the atomizer are subject to errors due to the fact that the droplet break-up mechanism requires a distance of about 0.5 m downstream of the atomizer to be complete.

The commercial atomizers studied included the TEEJET 11010 flat fan nozzle, the Micronair AU 3000 rotating basket atomizer, and the Beecomist 360 rotating porous sleeve atomizer (porous polyethylene sleeve with 40 μm diameter pores).

RESULTS AND DISCUSSION

Figures 3, 4 and 5 show droplet spectrum results for the three atomizers with water as the test fluid. All other conditions are indicated on the figures. The probe output data were first tested by applying the mass balance criterion, i.e., the flow rate of liquid into the atomizer equals volumetric flow rate of droplets out. After considerable analysis it was found that the OAP-260X probe gave consistently higher droplet flow rates than were supplied to the atomizer. This was attributed to "coincidence error", that is, the device is designed as a single-droplet measuring device. When two or more droplets are present at one time in the sampled volume, the droplet diameter reported is the sum of the two distinct diameters present in the sample volume. Resulting volume calculations are therefore erroneous. Data from this probe could not be used. Instead, previously obtained (2) photographic data at greater than 50 μm sizes were used to supplement the valid data from the FSSP probe (0.5 μm to 55 μm size range) to provide the results in Figures 3 and 4. Data from the FSSP on the Beecomist (Figure 5) showed that there were no droplets larger than 60 μm for this atomizer.

The three figures show data which can be summarized as follows:

1) The numbers of small droplets generated increases as the diameter approaches zero, down to at least 2.0 microns, in contradiction to the predictions of the widely accepted Nukiyama-Tanasawa distribution functions (2).
2) The Beecomist does the best job of producing a narrow droplet distribution spectrum (of the three atomizers tested).

3) The Mirconair does a moderately good job of producing a narrow spectrum at a high flow rate.

4) The usual spectrum statistic of average droplet size is of no utility in describing the spectrum for aerial spraying purposes because of the large number of small droplets. A new approach is therefore required, e.g. the mass fraction of droplets in the optimum size range for the particular target, and the mass fraction in the size range for off-target drift.

The results with respect to small droplet generation are well borne out by measurements on the off-target drift cloud from aerial spray field trials reported by Crabbe et al. (3) for droplet sizes below 20 µm. An additional field trial result (4) is that the optimum droplet size range for best spraying efficacy for spruce budworm control is between 15 µm and 50 µm delivered to the foliage. An examination of the above data shows that with an evaporation factor which causes about 50% reduction in diameter of the emitted droplet, provided viscosity and surface tension differences are not too great for formulations compared to water, the MICRONAIR produces twice as much mass of fluid in the right droplet range as does the Teejet (under the conditions of measurement). On the other hand, the Beecomist could be fed with a concentrated non-evaporating insecticide and generate three times the mass in the required delivered droplet size range based on the same feed rate (more atomizers would be required).

Additional experiments have been conducted to characterize atomizer performance, such as the effect of changing the wind speed, the atomizer rotational speed, and the properties of the fluid. In general, increased speed decreases droplet size, as does a reduction in droplet surface tension. Increased viscosity tends to increase droplet size. No general correlation is available as yet to describe atomizer performance. Additional data is available in Bontemps (1).

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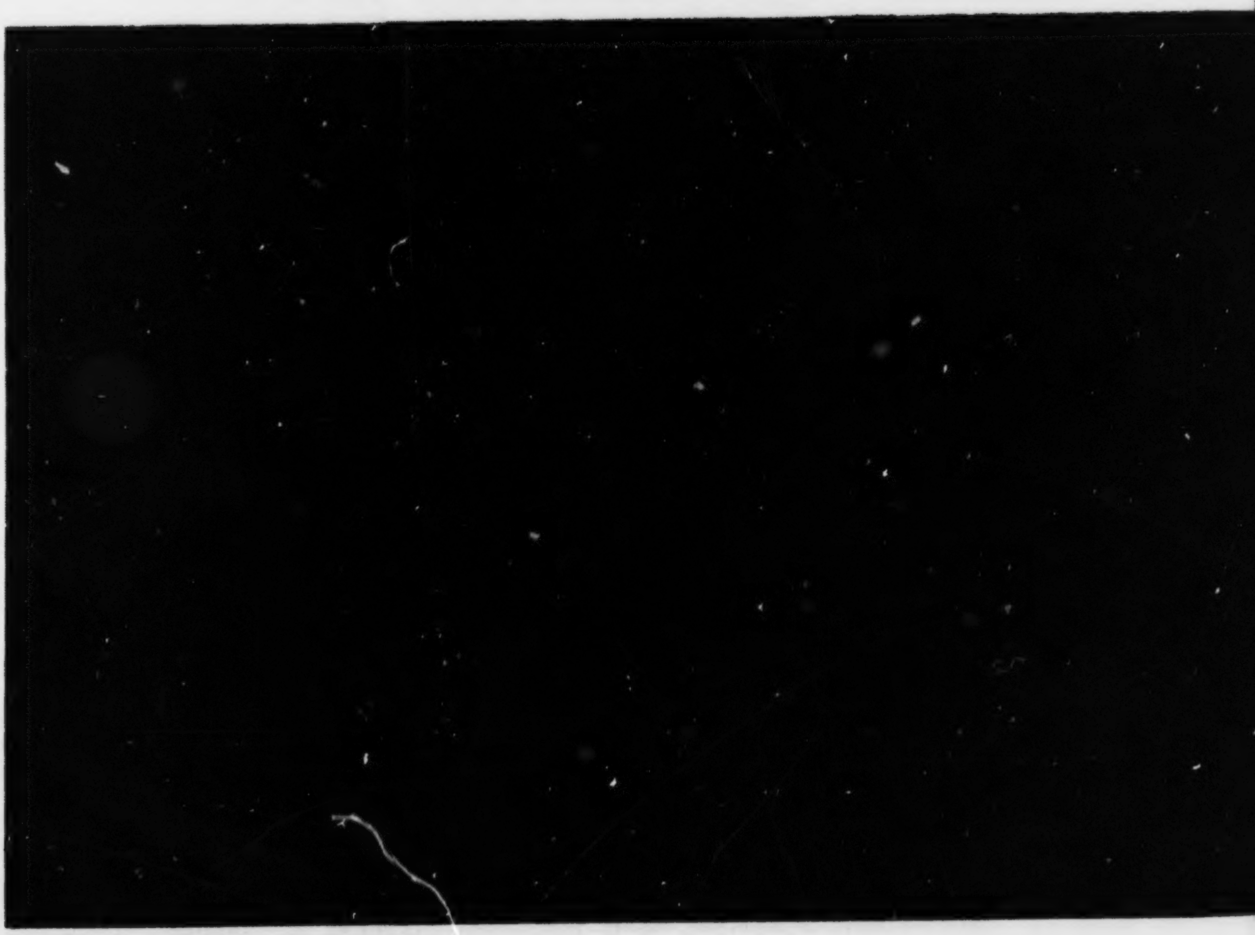

Figure 1. The test equipment, OAP-26 (right), FSSP-100 (left) particle data system (centre).

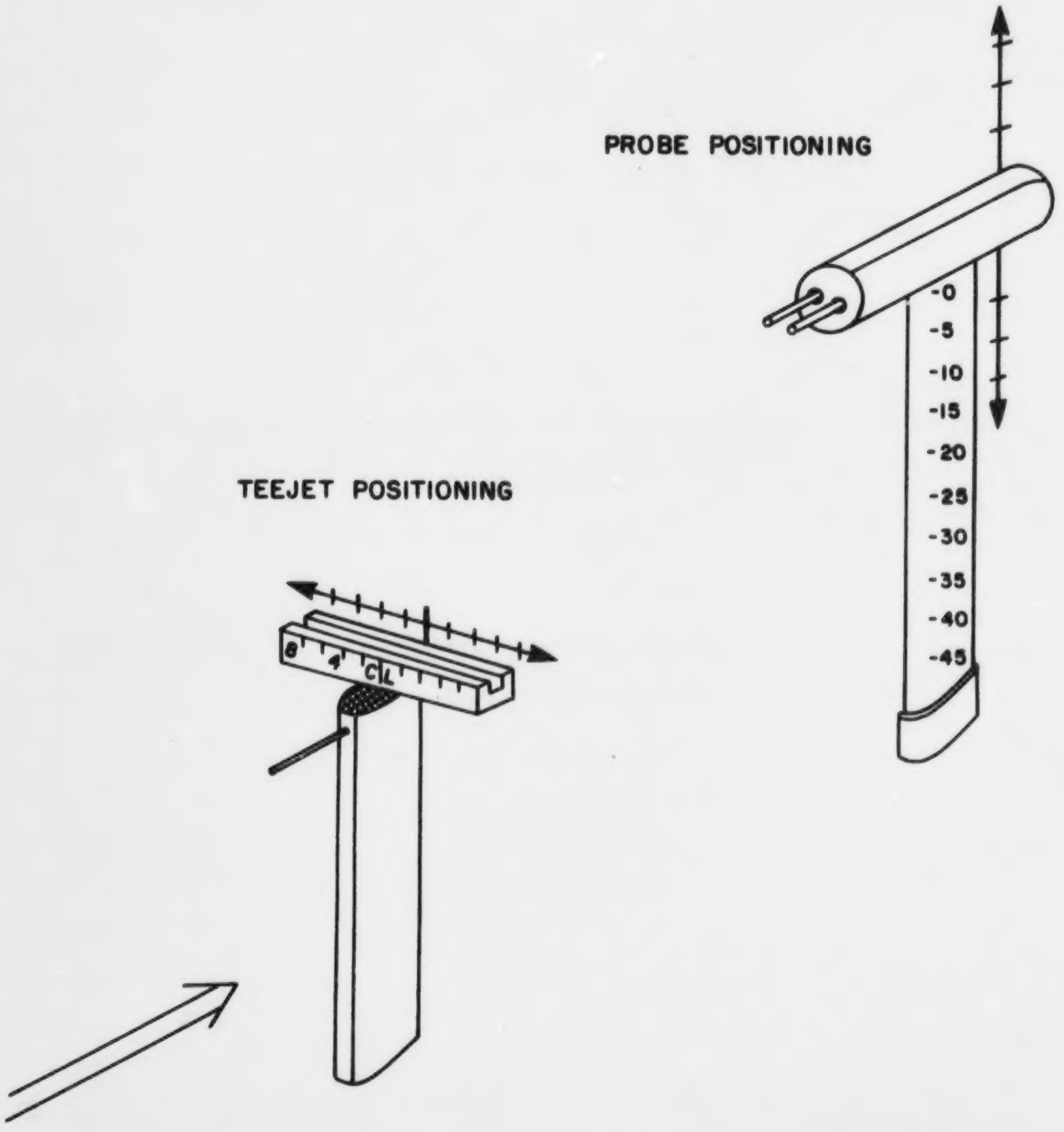
PROBE POSITIONING
-0
-5
-10
-15
-20
-25
-30
-35
-40
-45
TEEJET POSITIONING
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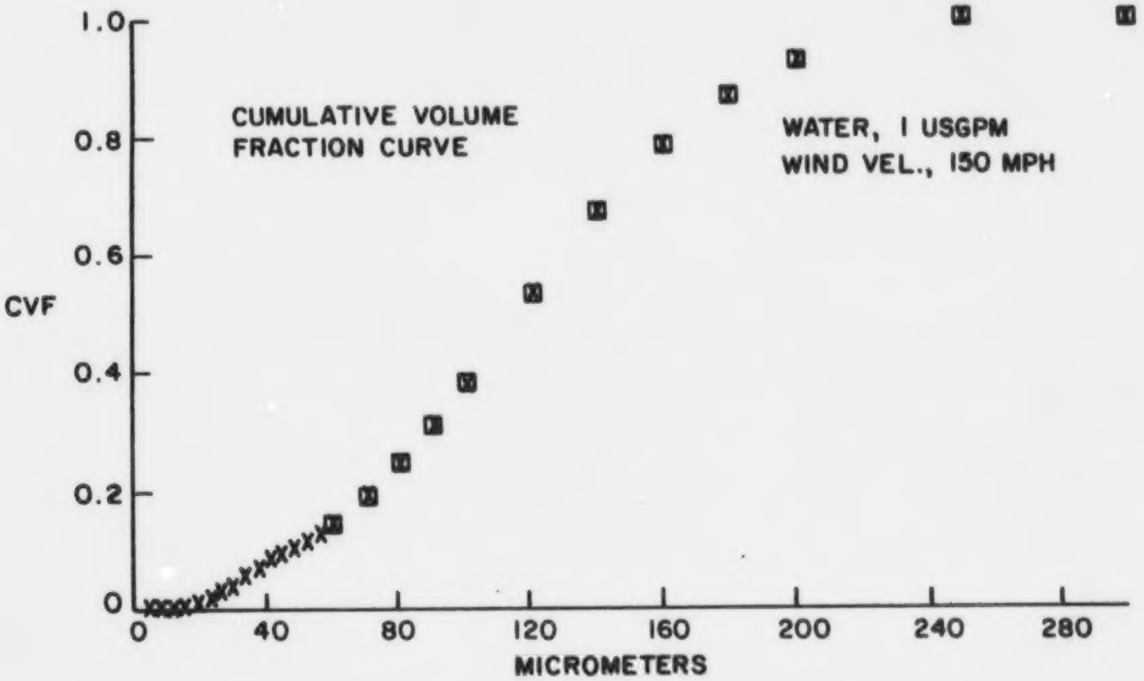
Figure 2. Traversing positioning method.



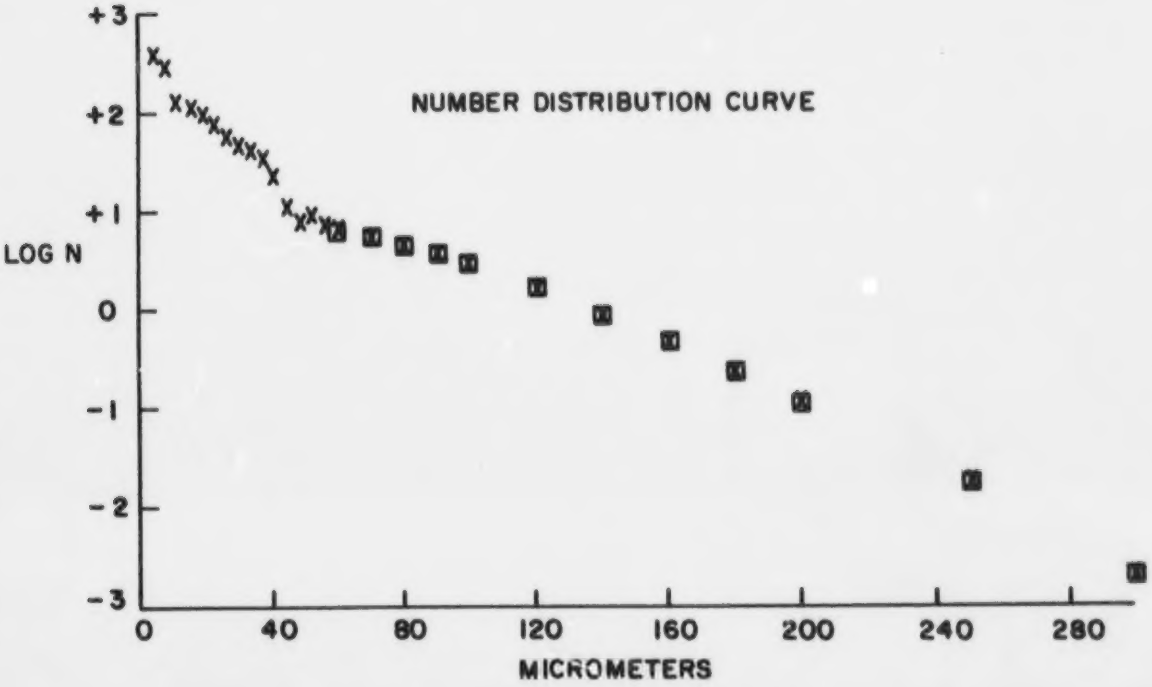


Figure 3. Data for TEE-JET 11010.

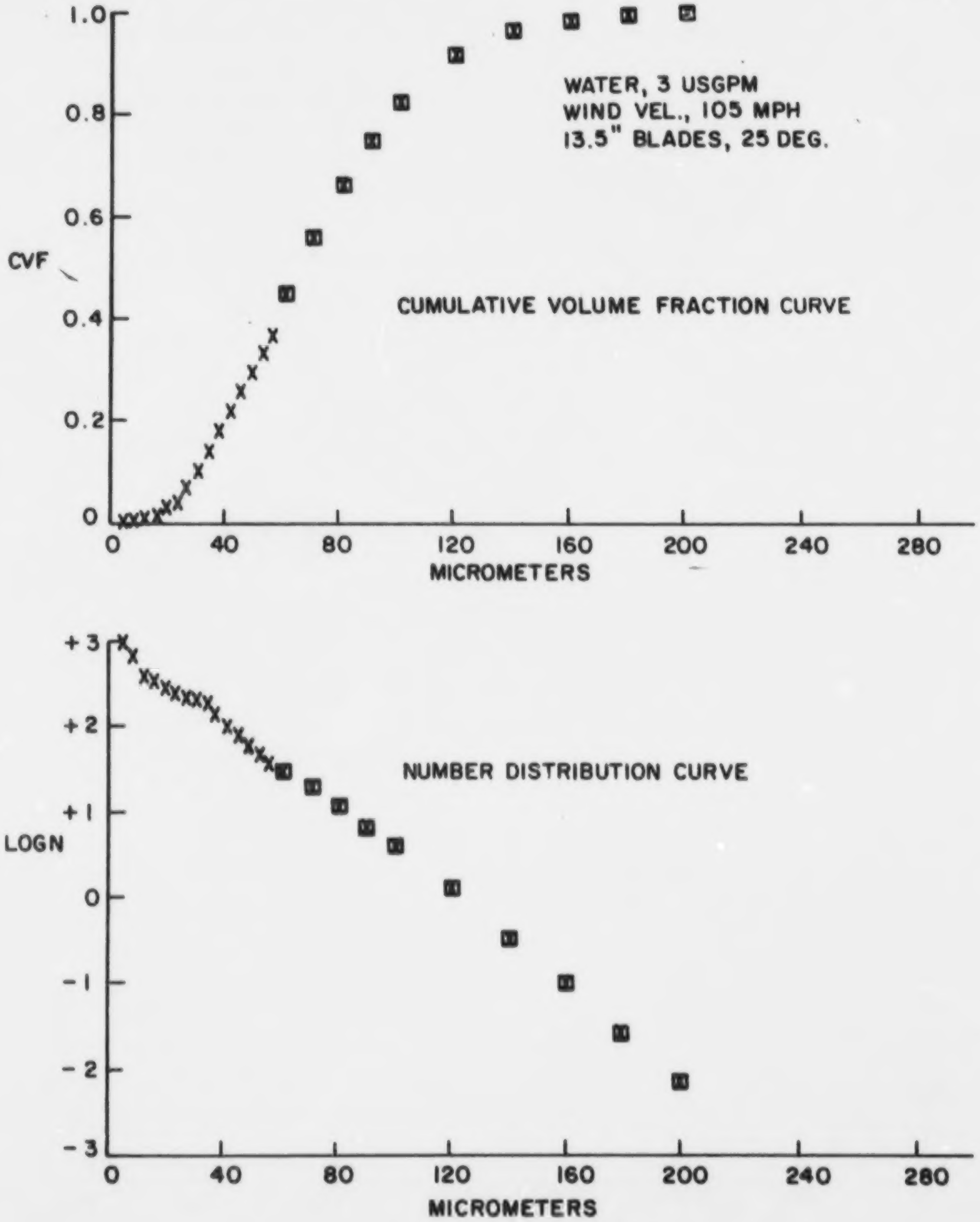


Figure 4. Data for Micronair AU 3000.

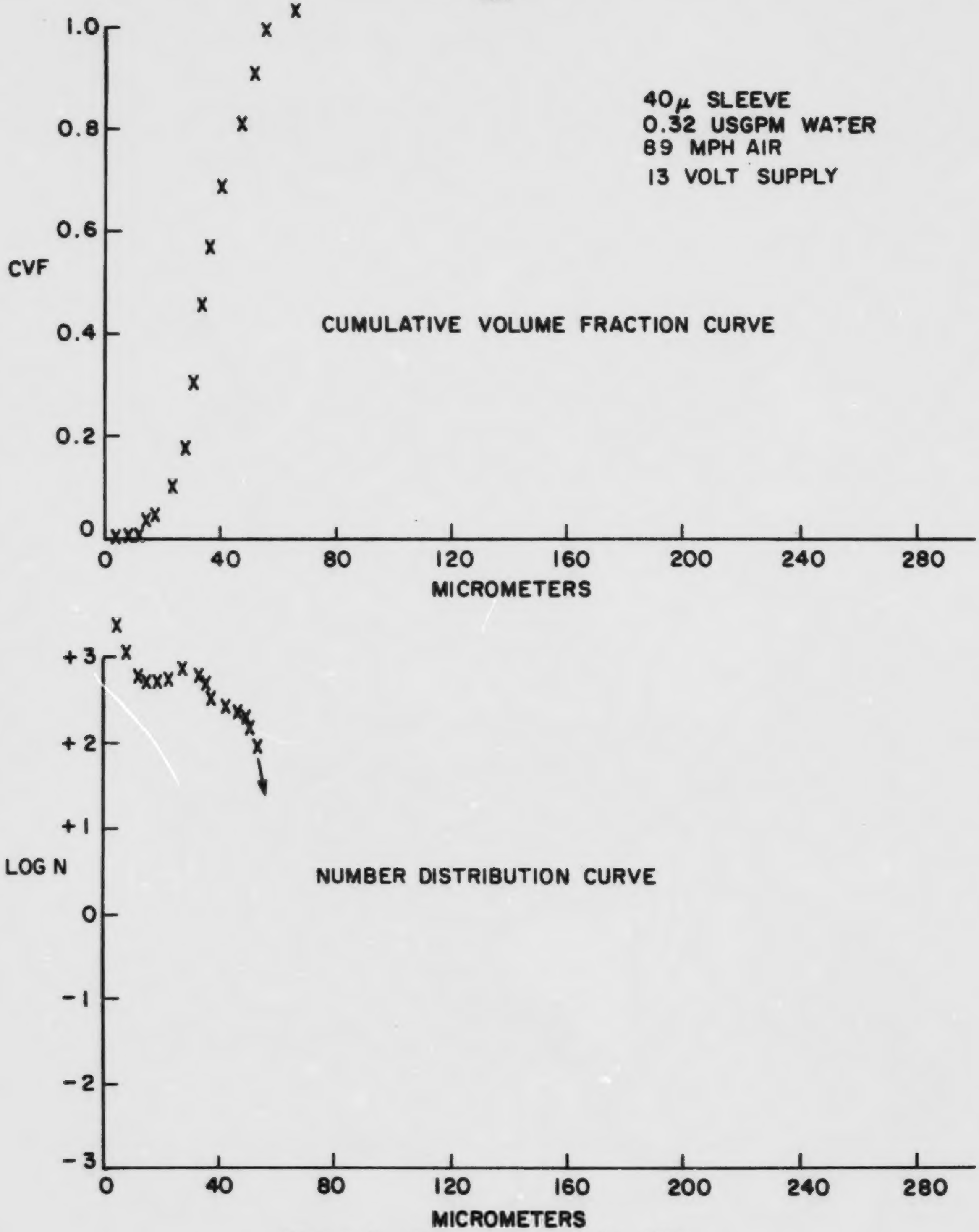


Figure 5. Data for Beecomist 360.

Poster Paper No. 7

THE INERTIAL IMPACTION OF DROPLETS ON FOLIAGE OF SOME CONIFERS

D.D. Kristmanson, J.J.C. Picot and G.W. Henderson
Department of Chemical Engineering
University of New Brunswick
Box 4400
Fredericton, N.B.
E3B 5A3

ABSTRACT

In aerial spraying of coniferous forests for spruce budworm control drops are deposited primarily by inertial impaction, their terminal settling velocities being considerably less than typical wind speeds in the canopy. In this work, the collection efficiencies of balsam fir and white spruce shoots have been measured using approach velocities of 52 to 185 cm/s and drop sizes of 9.5 to 55 μm. Several orientations were tested.

A method of predicting the efficiency with which a needle collects droplets is proposed in which a shelter factor related only to species, orientation and flow velocity and to the impaction efficiency of an isolated needle is used.

In New Brunswick, chemical insecticides in water-based emulsions are atomized by flat-fan sprays mounted on aircraft flying at speeds of up to 170 mph. The droplets after evaporation have a volume median diameter of about 55 µm. The terminal settling velocity of a 50 µm water droplet in air at 20°C (7.5 cm/s) is small with respect to typical air velocities in the canopy and it follows that drops in this size range must be deposited in foliage primarily by inertial impaction.

The efficiency with which drops are impacted upon the foliage of the target species becomes a crucial element in modelling the behavior of spray clouds. From knowledge of impaction efficiencies for isolated obstacles such as ribbons and cylinders it can be predicted that at typical wind velocities foliage elements will collect drops larger than 50 µm at efficiencies of 75% or more but that 10 µm drops and smaller, show much lower efficiencies. The needles of coniferous shoots will behave differently from isolated obstacles of simple geometry, making necessary the experimental measurements of drop collection efficiencies as function of drop diameter, air velocity and foliage type reported here.

PREVIOUS WORK

Droplet Deposition Studies

Little experimental work on this topic has been reported in the literature, and in no case to our knowledge has the impaction efficiency been measured directly. Typical field studies in which drop deposition has been observed and related to the most important physical factors include those by Barry and Ekblad (1978), Barry et al. (1977) and Armstrong and Yule (1978).

Wedding et al. (1978) examined particle deposition on a Douglas-fir canopy by measuring fluxes of monodisperse drops to an array of 50 trees of 0.76 m height mounted in a low speed wind tunnel. The work of Wedding and co-workers illuminates many aspects of droplet deposition but it was not designed to give the relationship required for our purposes, impaction efficiencies for individual shoots of spruce and fir with various drop sizes and approach velocities.

Aerodynamics of Flow Around Shoots

The aerodynamics of flow around vegetation has been of considerable interest to meteorologists and other scientists interested in the mechanics of the transfer of momentum, heat and mass to foliage. Aspects of this subject have been reviewed by Raupach and Thom (1981) and by Monteith and his collaborators (1975).

The drag coefficients of foliage elements assume importance in impaction processes. Since the shoot is porous, some of the approaching stream tube will flow through it and drops contained in the portion diverted cannot be captured. They are typically not large enough to diverge significantly from the streamlines around the shoot. A low drag coefficient would imply that most of the approaching stream tube is filtered by the shoot, a high drag coefficient that most of the fluid is diverted.

Drag coefficients of shoots of conifers have been measured by at least two groups of workers. Landsberg and Thom (1971) studied Sitka spruce and found that drag coefficient C, defined as:

$$F = \rho \; C \; A_V{}^2 \qquad (1)$$

where: F = drag force on a shoot

ρ = density of air

A = frontal surface area of the shoot

V = approach velocity of air

was approximately 0.5 to 0.3 at velocities from 50 to 300 cm/s. Shoots in this case were oriented with their upper face towards the velocity vector. In work done in this laboratory, drag coefficients of balsam fir shoots were found to be close to 0.5 at 45 to 185 cm/s.

Consider the stream tube approaching the shoot which would coincide with the envelope around it, if the shoots were not present. The "envelope efficiency" E_e will be defined as the fraction of the drops in the stream tube which deposit on the shoot. By simple momentum balance arguments the fraction of this stream tube which passes through the area defined by the envelope is given by $(1 + C)^{-1}$. This result shows that there is an upper limit of about 2/3 to 3/4 to the envelope efficiency. Actual efficiencies will be lower because some drops will evade capture as they are too small to impact efficiently on needles, and others will not encounter a needle in their passage through the shoot.

Mechanism of Capture by Simple Elements and by Foliage

The mechanics of impaction of drops on obstacles of simple geometry (cylinders, spheres, ribbons) was analyzed by Langmuir and Blodgett (1946). The fraction of the drops in the approaching stream tube which deposit on the obstacle (E_n) was shown to be a unique function of the Stokes number, defined as:

$$S = \frac{uV}{gD} \qquad (2)$$

where: u = terminal settling velocity of the droplet
V = approach velocity
g = gravitational constant
D = width of ribbon or cylinder

Later experimental results by May and Clifford (1967) showed slightly different results to the theoretical calculations of Langmuir and Blodgett. Their experimental data for ribbons have been used in the treatment of our results.

EXPERIMENTAL

Scope of Measurements

The measurements made of foliage collection efficiency covered the parameters described below.

(i) Foliage: single shoots of balsam fir and white spruce.

(ii) orientations of velocity vector: "normal" to upper face of shoot, towards bud parallel to stem ("end"), at 45 deg. to the upper face ("oblique") and normal to the stem edgewise ("edge").

(iii) Drop Sizes µm: 9.5, 37, 55

(iv) Air Speeds m/s: 0.52, 1.06, 1.85

Apparatus

A small wind tunnel was used. The working section was a 0.197 m inside diameter plexiglass tube. The entry was designed to provide a well-mixed and uniform flow of droplets and air. Velocity measurements at the position at which shoots were mounted gave profiles which were flat within ± 5% of mean flow up to 1.6 cm from the walls. Turbulent intensity was less than 0.7%.

The shoots were supported on a fine wire grid in a central position. A strip of Kromekote paper about 1 mm wide was mounted on a thin wire 7.0 cm upstream to determine the upstream flux of drops. Drops were formed by a Bergman-Liu Monodisperse Drop Generator (Model 3050) using Number 2 fuel oil containing a dye.

Collection Efficiencies

The concentration of drops in the approaching airstream was determined for each run by the strip of Kromekote card mounted upstream of the shoot. The drops collected during the run were counted and the upstream flux of drops was estimated using the May and Clifford (1967) correlation for collection efficiency of ribbons. The collection efficiencies were calculated both on the basis of the envelope area (Ec) and on the needle area (En).

A typical envelope efficiency - Stokes number plot (Figure 1) shows results for three drop sizes and three approach velocities. Twenty seven shoots were used in this test, i.e. three replicates at each set of conditions. This result is for fir shoots oriented normal to the air velocity vector. The Stokes number is based on approach velocity and needle width. Scatter of points is typical of the results obtained in these tests.

Smoothed curves are shown for fir (Figure 2) at four orientations and spruce (Figure 3) at three orientations.

Needle Efficiencies and Shelter Factors

An alternative method to describe the collection efficiency is to base it on the area of individual needles rather than the envelope area. The needle efficiency can be defined as:

$$E_n = \frac{\text{drops collected per unit area per unit time}}{\text{upstream drop flux}}$$

Let the May-Clifford efficiency for a ribbon of the same width as an average needle be E_t.

A shelter factor, f, which represents the reduction in single needle efficiency caused by diversion of streamlines, interference between needles and other effects is defined:

$$E_n = f\, E_t \tag{3}$$

The factor f is relatively independent of the droplets and fluid properties and is mainly dependent on the approach velocity and geometry of the shoot. The inertial impaction processes are accounted for by the E_t term. It is not possible to separate these variables completely but in practice it is advantageous to correlate the results in this way because of the simplicity with which needle efficiencies can be predicted. That is, given the approach velocity, the shelter factor f can be calculated for the species and orientation, the May-Clifford efficiency can be obtained from the properties of the droplet and the air, the approach velocity and the needle efficiency from the product of f and E_t.

Shelter factors were calculated for all results and for each specific combination of species and orientation. They were plotted against approach velocity, V. The best straight line of the form:

$$f = a + bV \qquad (4)$$

was drawn through the points. A computer program was written to compare needle efficiency observed and that predicted from the use of equations (3) and (4) and the May - Clifford impaction efficiency curve for ribbons. The standard deviations of the differences between the observed and calculated values were calculated and adjustments were made in a and b to minimize these values. The results (Table 1) demonstrate that the needle efficiencies for the ranges of drop sizes and approach velocities studied can be satisfactorily predicted by this method.

This treatment of the data tends to predict lower needle efficiencies than observed for the 9.5 μm drops. Experimental difficulties in determining the upstream flux of drops reduce the accuracy of those measurements. The impaction efficiency of the Kromekote strips used is low and there is significant scatter in the results presented by May and Clifford for these low Stokes numbers. In addition, when droplets are so much smaller than the needle, surface irregularities on the needles will play a larger role than with larger droplets and higher efficiencies than implied by this treatment can be expected.

CONCLUSION

1. These measurements have shown that the envelope efficiencies of fir and spruce shoots at several orientations to air flow can be

correlated against Stokes number based on approach velocity and average needle width. In the case of fir shoots, oriented normal to the flow, the envelope efficiency approaches a limit at higher Stokes numbers slightly lower than that predicted from an argument based on diversion of streamlines by drag of the shoot.

2. The needle efficiencies of spruce and fir shoots have been satisfactorily correlated with the product of the inertial impaction efficiency of an isolated ribbon of the same diameter as an average needle and a shelter factor dependent only on the approach velocity, species and orientation.

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Table 1 Constants in Eq. (4)

Species	Orientation	a	b	S.D.
Fir	Normal	.46	0	.073
	End	.213	.044	.025
	Edge	.095	0	.015
	Oblique	.290	.0804	.057
Spruce	Normal	.244	.1053	.046
	End	.140	.046	.042
	Oblique	.298	0	.065

Units of b are m^{-1} s

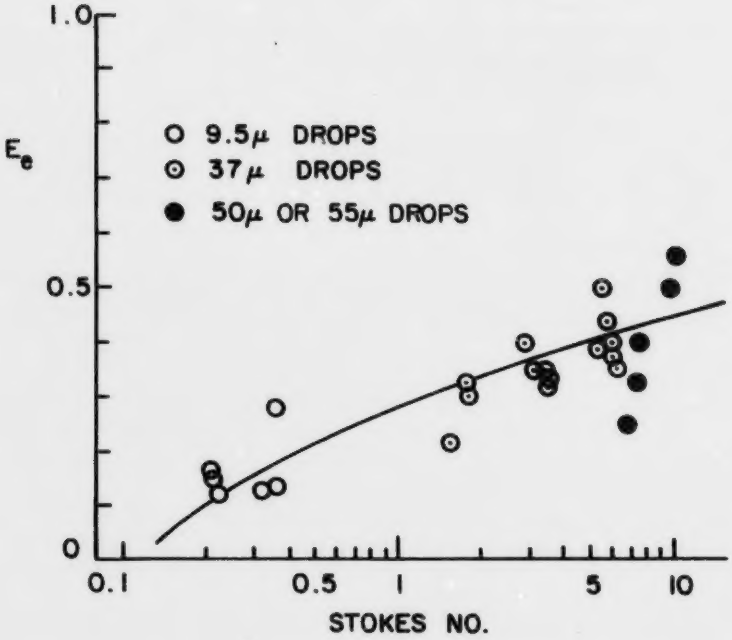

Figure 1. Envelope efficiency vs Stokes number based on needle width. Flow normal to fir shoot.

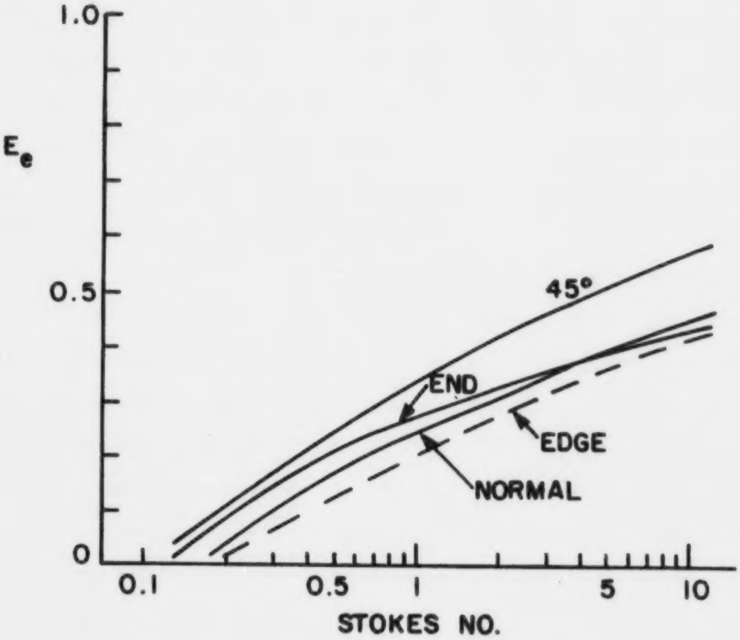

Figure 2. Envelope efficiencies for fir.

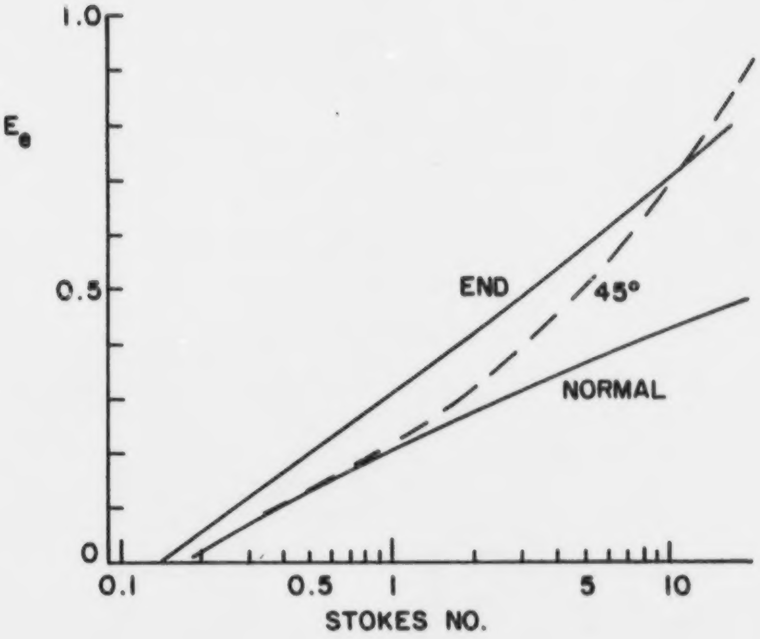

Figure 3. Envelope efficiencies for spruce.

Poster Paper No. 8

WEATHER AND PESTICIDE APPLICATION

G.B. Atkinson[1] and R.F. Hopkinson[2]
Scientific Services Division, Central Region
Atmospheric Environment Service, Environment Canada

[1]. Room 1000, 266 Graham Ave. Winnipeg Manitoba R3C 3V4
[2]. Airport Terminal P.O. Box 4080. Regina Saskatchewan S4P 3W5

INTRODUCTION

Whenever any agricultural pesticide is applied to a target field as a spray from either a groundrig or an aircraft, there is drift of some of the active ingredient away from the target. Initially this takes the form of droplet drift with the smaller size droplets being preferentially wafted downwind rather than being deposited on the target. Then following the application and extending over a few hours, more pesticide is carried downwind as vapor, both from airborne droplets evaporating and from evaporation of the pesticide which reached the target. Vapor drift depends on the pesticide vapor pressure and the soil, air and plant temperatures in the target area. Droplet drift depends on the factors listed in Table I.

The non-meteorological parameters which affect spray drift are not truly independent of the atmosphere; it is just that meteorology is not the dominant factor. For instance, it is the movement of the air past the aircraft and the intensity of the wing tip and other vorticies which makes placement of the boom and nozzles so critical to achieving an even spray pattern. Droplet volatility depends on air temperature. Droplet size is a function of many factors such as spray pressure, nozzle type and orientation, viscosity of the liquid, etc. Drift is very dependent on droplet size (Table 2). In practice with conventional nozzles, it is not possible to produce droplets of a uniform size. Instead, a broad spectrum of drop sizes is generated (centred on the desired size with the smaller droplets having the greatest potential for off-target drift).

To minimize any potential spray drift damage, spray aircraft usually:

a) release the spray into the aircraft downwash area,
b) release the spray so that it avoids vortices generated by the aircraft:
    1) for fixed wing aircraft, the boom should be no more than 3/4 of the wing length to avoid wing tip vortices and the boom should be 30 cm or more below the wing,
    2) for rotary wing aircraft, the boom should be no more than 3/4 of the rotor length to avoid the tip vortex and should be placed as far forward as possible,
c) reduce aircraft weight to reduce speed which decreases the strength of the vortices generated by the aircraft,
d) fly as low as is practical,
e) use additives to increase spray viscosity and/or vapour pressure,
f) use as large a droplet size as possible by:
    1) increasing nozzle orifice size,
    2) reducing spray pressure,
    3) using additives to increase viscosity.

WIND SPEED

The amount of pesticide lost from the target area, and the distance it moves, both increase as wind velocity increases, so increased wind velocity will generally cause more drift. However, severe drift injury can occur with low wind velocities, especially under temperature inversion situations (see stability section).

In Table 3, note that even with winds above 60 km/h, a 240 µm droplet (assuming it doesn't change size) would only drift a little more than 100 m if it fell unhindered to the ground. Turbulence will hinder some of the spray, however. Intuition suggests that about half the spray is brought closer to the ground by turbulence eddies and half is carried further away from the ground, than would be the case if the turbulence didn't exist. It is the turbulence associated with the higher wind speeds which can cause a drift problem and reduces application efficiency.

WIND DIRECTION

Spraying along a path at right angles to the wind is most efficient for the even dispersion of the pesticide into the crop. This might mean more passes over the field if the wind was blowing diagonally across the field, but the more even application might make the extra passes worth while.

Spraying with the wind direction close to the spray path will generally increase drift injury potential; both because of the nearness of the end of the spray line to the edge of the field, and because of the accumulative effect of the wind blowing along the spray path.

Pesticides should not be applied when the wind direction is blowing toward an adjoining susceptible target, nor if the wind is expected to shift in the near future towards this susceptible target. Check the forecast. Significant amounts of vapor can evaporate from a field for 2 to 3 hours after spraying if temperatures are high enough. Trees and hedgerows on the edge of fields can make excellent filters of the airstream passing through them. Thus, they can accumulate a large amount of pesticide coming off a field. In calm conditions, it is virtually impossible to determine the direction of drift. It is rare for air to be absolutely calm and pesticide applied could drift in an unexpected and unwanted direction. Thus, a light wind is desirable so that the direction of drift can be determined before application.

RELATIVE HUMIDITY

Relative Humidity (RH) affects the rate of evaporation of water from liquid drops. The lower the RH, the faster the loss of water and the smaller the drop becomes. The smaller the drop, the slower it falls; the slower it falls, the further it drifts. In a few seconds, if they do not impinge on target or on some object off-target, the water and the solvent evaporate completely, leaving a miroscopic droplet composed only of the pesticide and any other low-vapor-pressure components in the spray (Table 4). These tiny droplets, of course, can drift for long distances. Ultimately these components also evaporate but that is not necessarily the end of the problem, for vapors in sufficient concentration can also do injury to off-target plants.

AIR TEMPERATURE

High temperatures, like low relative humidity, will cause more rapid evaporation of spray droplets between the sprayer and the target than will low temperatures. Again, the faster the droplet size diminishes, the further it will drift.

Temperature also has a strong influence on the volatility of pesticides. For example, 2,4-D is available in esters of widely varying volatility, from non-volatile to relatively high volatility: the vapor release from a certain high volatile ester of 2,4-D would approximately triple with a temperature increase from 15°C to 26°C.

Temperature also affects the response of plants to the vapors of pesticides, and presumably also their response to the liquid spray as well. In general, the higher the temperature the more likely the same amount of off-target drift is to cause plant damage.

STABILITY

The lower levels of the atmosphere, particularly those nearest the surface of the earth, are full of eddies. Stability is an attempt to quantify the size and energy of those eddies. When the eddies are small and have little energy, the air is stable. To the pilot, flight is smooth. When eddies are large, and have significant energy, the air is said to be unstable. Flight will be bumpy.

These eddies can be produced in two ways. When winds are strong, that is, above approxmately 20 km/h, the boundary layer of the atmosphere, near the surface of the earth, will be full of strong eddies. These eddies are caused by friction with the surface of the earth, and by obstructions such as trees and buildings. Pilots also know this as mechanical turbulence.

When winds are not strong enough to throughly mix the air, the amount of energy in the eddies is governed by the temperature structure of the boundary layer of the atmosphere. If the eddies are large and energetic for this reason, flight is again bumpy and it is known as thermal turbulence.

When does thermal turbulence occur? It comes about when the sun strongly heats the ground which in turn heats the air near the ground. It is analogous to a pot of water on a stove: the lower portion of the atmosphere boils; and the stronger the heating, the harder it boils. This temperature structure where the warmest air is near the ground and the temperature decreases rapidly with height, is often called lapse conditions. This is the most common condition during sunny summer days.

When the lower atmosphere is well mixed, as is the case when winds are strong (but not necessarily only then) the temperature drops off uniformly with height at a rate of approximately 1°C per 100 metres (3°C per 1,000 feet). This is commonly called the neutral condition.

If the temperature structure is the reverse of these and increases with height the condition is called an inversion. This is because the normal change of temperature with height is inverted; that is, the air is colder near the ground and warmer above. Under inversion conditions the energy in the eddies is quickly damped, and flight is smooth.

Why is the concept of stability important to spray operations? It is because, when the energy of the eddies is high and the air is turbulent, the amount of spray reaching the target is lower; that is, the efficiency of the spray operation is least because a greater amount of spray is carried upward. This also implies of course that the spray drift is highest when the air is turbulent, and that is true. However, because this drift is spread through a greater depth of the atmosphere, this is not necessarily the case which will result in the greatest off-target plant injury.

Consider the case where an inversion condition exists. Winds would be light and may even be calm. Efficiency of the spray operation is probably highest. However the spray drift and vapor drift which does occur will remain concentrated in a shallow layer near the ground. An analogy would be the smoke from a smouldering fire late on a summer's evening, which rises a meter or less off the ground and then drifts horizontally for long distances without dispersing. Severe injury can occur when such an undispersed spray plume leaves the target area. One paper states that "three times more spray drifted 30-60 m and 10 times more drifted 300-600 m under inversion conditions as compared to lapse conditions with a given wind speed."[1] Inversion conditions with light or no winds are desirable only for aerosol application (small droplets) for flying insect control.

Undoubtedly the paradox in the light wind situation has already been noted. When spray efficiency is high, the risk of a concentrated drift plume is high. When efficiency is least, the spray not reaching the target is well dispersed upward in the atmosphere. It appears that at the present time it is not possible to say in which condition, lapse or inversion, the risk of off target damage is greater.

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[1] A. Dexter; Herbicide Spray Drift; North Dakota Cooperative Extension Services Circular A-657.

The in between state, the neutral condition, appears to neither trap the spray drift near the ground nor carry larger amounts of spray upward away from the target. Unfortunately this temperature regime is most often associated with high winds, but it does occur in other situations. The most useful other situation to know about is in the morning when the typical overnight inversion is being destroyed by the sun's heating. A knowledgeable Saskatchewan resident says that the practice of aerial applicators is to delay spraying in the morning until the dust from traffic on the rural roads begins to lift and break up instead of lying flat in the ditch. This would be an excellent indication of the break down of the night-time inversion, and it usually is a few hours from this time until winds begin their usual daytime increase. This time of day, after the inversion has begun to break up and before winds have increased, would be the best time of day to spray those areas with the greatest potential to cause drift damage. It seems to be the practice in South Dakota to not completely spray one field before going on the next, but to spray the most hazardous strips of all the fields to be done that day in the mid morning. This makes sense since this would be time of neutral stability in a light wind situation. This would involve keeping track of what had been sprayed and what had not, but if it avoided even one legal suit due to spray drift, it would be worth it.

Table 4 attempts in broad terms to indicate the efficiency of aerial application of agricultural pesticides with different wind speed classes and temperature regimes. Here efficiency refers to the percentage of the spray reaching the target.

Table 5 attempts in broad terms to indicate the potential for off target spray damage to occur with different wind speed classes and temperature regimes.

Figures 1 and 2 illustrate in an approximate fashion three typical situations.

SUMMARY

To minimize drift, use as large a droplet size as practical. Avoid relative humidities less than 60%. Avoid high temperatures associated with the heat of the day. A desirable wind range is from 5 to 20 km/h. Winds much above 20 km/h will drastically reduce spray efficiency. Spray at a large angle to the wind, starting at the downwind edge of the field and move succesive passes upwind. Avoid spraying during a temperature inversion, especially if the droplet size is small (less than 100 micrometres). Neutral stability (associated with moderate winds or light winds accompanied by mid-morning heating) presents the best compromise between spray efficiency and potential spray drift damage.

The least favourable conditions for efficient spraying exist during the afternoon on a sunny day (i.e. temperature is highest, RH is lowest, wind tends to be strongest, and thermal turbulence (strong lapse) is greastest).

FURTHER INFORMATION

For more assistance in understanding the effects of weather on aerial spraying contact a Scientific Services Office of Atmospheric Environment Service in: Vancouver, Edmonton, Regina, Winnipeg, Toronto, Montreal, Fredericton, Halifax, St. John's.

AVIATION WEATHER FORECAST AND ADVICE

Weather offices can often be of assistance particularly with the detailed forecasting of wind speeds. Consultation is available from offices providing aviation weather briefing services in your area.

Table I. The Influence of Various Factors on Spray Droplet Drift

Factor	More Drift	Less Drift
Non-Meteorological:		
Physical arrangement of boom and nozzles	?	?
Release Height	Higher	Lower
Droplet Volatility	Volatile	Non-Volatile
Droplet Size	Smaller	Larger
Meteorological:		
Wind Speed	Higher	Lower
Wind Direction	Low Angle to A/C	High Angle to A/C
Relative Humidity	Lower	Higher
Air Temperature	Higher	Lower
Stability	Inversion	Lapse

Table 2. Influence of Droplet Size on Potential Distance of Drift

Droplet Diameter (Micrometers)	Type of Droplet	Time Required to Fall 3 metres (Seconds)	Lateral Distance Droplets Travel in Falling 3 metres in a 5km/h wind (metres)
5	Fog	3960	5000.0
20	Very fine spray	252	335.0
100	Fine spray	10	13.0
240	Medium spray	6	8.5
400	Coarse spray	2	2.6
1,000	Fine rain	1	1.4

Table 3. Distance Travelled in Falling 3 m for Various Wind Speeds for a 240 Micrometre Droplet (ignoring turbulence)

Wind Speed	(km/h)	1	2	4	8	16	32	64
	(kt)	0.5	1.0	2.0	4.0	8.0	17.0	34.0
Distance	(m)	1.6	3.3	6.7	13.3	26.7	53.3	106.7

Table 4. Time and Vertical Fall Distance Necessary for Pure Water Droplets to Lose 90% of their Volume by Evaporation at 26°C (after Akesson and Yates, 1973)

		Relative Humidity			
		30%		70%	
Beginning Droplet Diameter (µm)	Final Droplet Diameter (µm) (10% of Original Volume)	Time (sec)	Fall Distance (m)	Time (sec)	Fall Distance (m)
100	46	4.2	.75	9.2	1.60
80	37	2.8	.25	6.3	.67
60	28	1.7	.13	3.8	.23
40	19	0.8	.10	1.8	.15

Table 5. Spray Efficiency and Weather

	Temperature Structure		
	Inversion	Neutral	Lapse
Wind Speed km/h	- early evening to shortly after sunrise - never in summer with strong winds	- briefly after sunrise and late in afternoon - during day with heavy overcast	- during day and especially afternoon - never with strong winds
Less than 5	Highest	High	Moderate
5 to 20	Moderate	Moderate	Low
More than 20	(Doesn't occur)	Lowest	(Doesn't occur)

Table 6. Spray Drift Damage Potential and Weather

	Temperature Structure		
	Inversion	Neutral	Lapse
Wind Speed km/h	- early evening to shortly after sunrise - never in summer with strong winds	- briefly after sunrise and late in afternoon - during day with heavy overcast	- during day and especially afternoon - never with strong winds
Less than 5	High	Moderate	Low
5 to 20	Moderate	Moderate	Low
More than 20	(Doesn't occur)	High	(Doesn't occur)

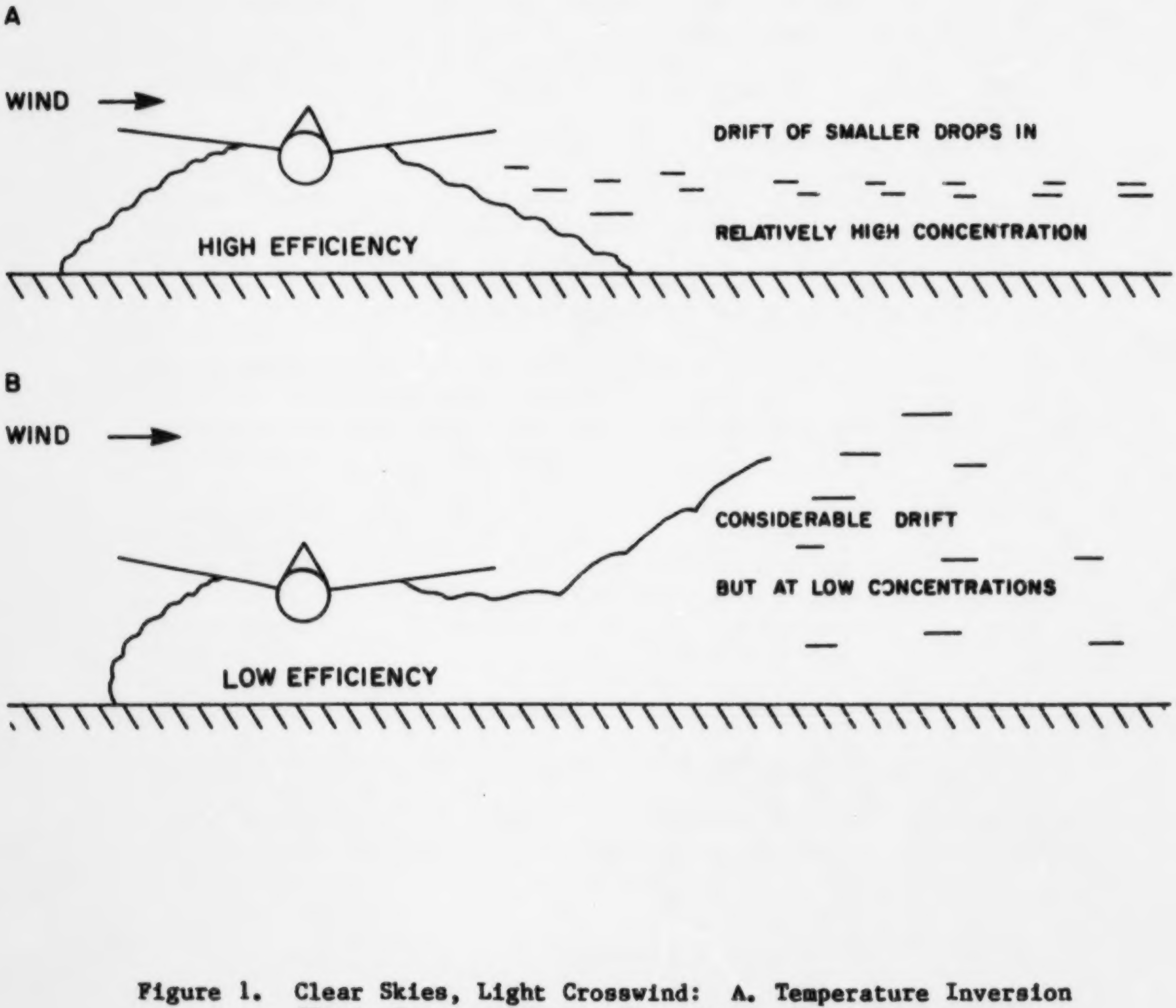
A
WIND
DRIFT OF SMALLER DROPS IN
HIGH EFFICIENCY
RELATIVELY HIGH CONCENTRATION
B
WIND
CONSIDERABLE DRIFT
BUT AT LOW CONCENTRATIONS
LOW EFFICIENCY

Figure 1. Clear Skies, Light Crosswind: A. Temperature Inversion (Early Evening Untill after Sunrise); B. Temperature Lapse (During Day Especially in the Afternoon).

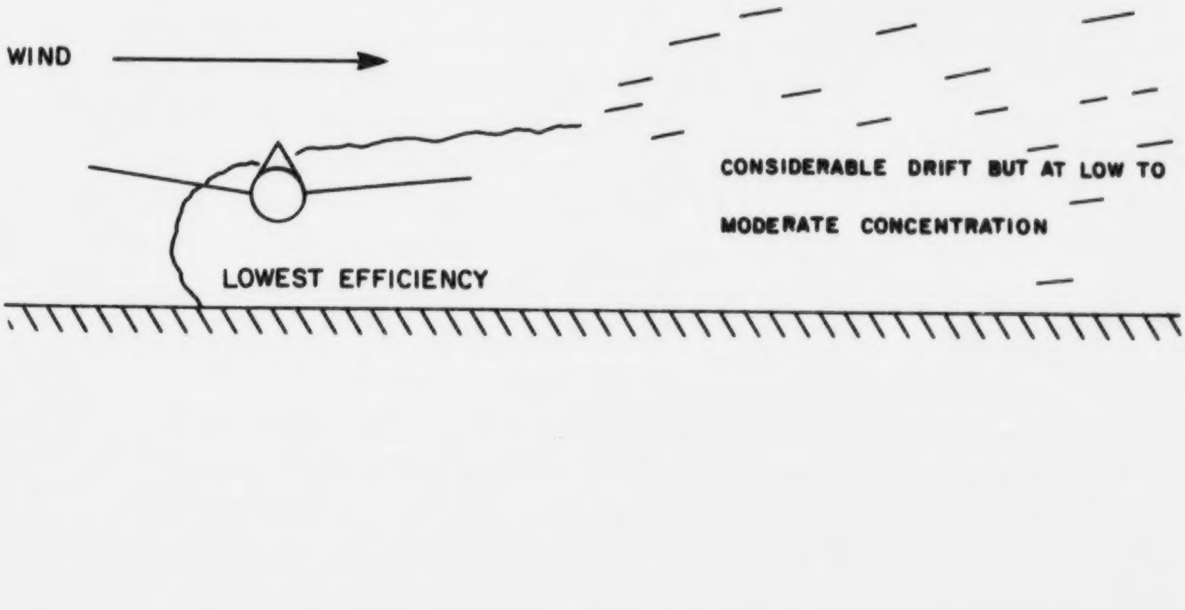
WIND
CONSIDERABLE DRIFT BUT AT LOW TO
MODERATE CONCENTRATION
LOWEST EFFICIENCY

Figure 2. Strong Crosswind at any Time.

Poster Paper No. 9

EFFECT OF ATMOSPHERIC TURBULENCE ON WINDBORNE DRIFT OF AERIAL FOREST SPRAYS

R.S. Crabbe
National Aeronautical Establishment
National Research Council
Ottawa, Ontario
K1A 0R6

ABSTRACT

Five aerial forest spray trials in New Brunswick are described in terms of the effect of atmospheric turbulence on windborne droplet drift from ultra low volume applications. A single line was treated using an operational spray plane, flying at ~40 m (metres) above ground level, and an aqueous spray formulation in which dibutyl phthalate replaced the active ingredient fenitrothion, but whose physical properties including droplet size spectrum are considered to be substantially unaltered. The spray plane was equipped with Teejet atomizing nozzles. Sampling equipment to collect windborne active ingredient was deployed on masts and scaffolds at 20 locations and from tethered blimps at three locations at heights from 10 m to 175 m above ground level to a distance of 1200 m from the flight line. Meteorological conditions measured on site varied from weak instability to strong stability.

Analysis of the field data indicates that the meteorological conditions favouring complete deposition of ultra low volume spray droplets within 1 km of the flight line are turbulent mixing layers produced by either near-neutral temperature stratification

with moderate wind speeds or convective activity beneath a low inversion base with light wind speeds. Under these conditions, the turbulent transfer velocity of windborne droplets into the canopy flow attains values of 7-8 cm s^{-1} (larger than the droplet terminal velocities) resulting in less than 5% of the active ingredient being still airborne at 1200 m from the flight line.

The meteorological conditions favouring the least deposition are characterized by sufficient thermal stability to suppress atmospheric turbulence. Under these conditions, produced by clear overnight sky conditions and light winds, the turbulent transfer velocity is vanishingly small resulting in more than 15% of the active ingredient still being airborne at 1200 m from the flight line.

A prototype six-stage cascade impactor was introduced in these trials to measure the ULV droplet size spectrum in the canopy flow. When compared to the foliar deposit droplet size spectrum measured by the New Brunswick Research and Productivity Council, the impactor-measured spectrum was larger in the 0-15 μm diameter range but smaller in the 15-50 μm diameter range. This result is attributed to the size-selective collection efficiency of fir needles (2-3 mm width); droplets smaller than 15 μm diameter, which appear in large numbers in the Teejet spectrum, have too low an impaction efficiency to justify their inclusion in the spray emission. The aerodynamic analysis of the impactor deposits will be briefly described.

INTRODUCTION

Aerial forest pesticide sprays in Canada are conducted in thermally stable atmospheric conditions of early morning and late evening in the belief that such practice reduces off-target windborne droplet drift. The difficulty with this approach is three-fold. First, the small diameter droplets comprising the current ultra low volume (ULV) spray have low sedimentary deposition and are therefore susceptible to wind drift in the absence of turbulence to transport them into the canopy flow. Second, stable conditions are frequently characterized by a rapid increase of wind speed with height so that even if surface conditions are calm, the wind drift at the spray height may be larger than in the 'breezy' surface conditions of the turbulent atmosphere. Third, the decay of atmospheric turbulence from overnight ground cooling is associated with stable density stratification which reduces the descent speed of the aircraft vortex wake containing the spray emission and exacerbates their windborne transport off the target. However, in spite of these obvious disadvantages of early morning sprays, provincial legislation in some regions still favours aerial dissemination of pesticides at dawn.

This paper presents the results of a controlled field experiment in New Brunswick in 1983 by the NRC Unsteady Aerodynamics Laboratory (UAL) to demonstrate that the optimum meteorological conditions for suppression of windborne droplet drift and maximization of target deposit are turbulent. Results of a previous field experiment in New Brunswick (Crabbe et al., 1983) had indicated less long range wind drift from ULV aerial spray emissions when the atmospheric surface layer was slightly unstable to neutral (moderately turbulent) than when it was slightly stable (weakly turbulent). The difference was tentatively attributed to the increase of downward turbulent transfer of spray droplets drifting beyond the near field, i.e, following vortex dissipation, in unstable to neutral flow relative to that in stable flow. The most recent study (the subject of this paper) documents the effect of turbulent transfer, in terms of the measured turbulent deposition velocity, in suppressing wind drift over a range of meteorological conditions varying from slightly unstable, through neutral to close to the stable limit of zero atmospheric turbulence. The experiment is described in detail in Crabbe et al. (1984).

TEST SITE AND INSTRUMENTATION

The test site, located near Upper Blackville, N.B., (46°35', 66°50') is covered by a largely second growth jack pine-spruce forest of variable height (10-15 m) and density. The site is level and homogeneous for several kilometres in all directions. The sampling grid and spray line are shown in Figure 1. The spray droplet samplers comprised UAL six-stage cascade impactors (Crabbe, 1984) to measure the droplet size spectrum from 0-50 µm diameter in the canopy flow and pump-aspirated 4-mm I.D. glass tubes containing a length of chromatographic packing material to trap windborne droplets (Crabbe et al. 1984). The latter are referred to as dosimeters inasmuch as they measure the vertical profile of the time-integrated atmospheric concentration or dosage, of spray droplets during drift cloud passage, necessary for windborne drift computations. Droplet size spectrum measurements in the 20 to 120 µm diameter range were effected by the University of New Brunswick (Picot, 1983 and Kristmanson, 1983) using Rotorods in the canopy flow.

The UAL deployed their dosimeters at 10 m and 17 m above ground level (agl) on the TV masts and at discrete heights to 175 m agl from blimps tethered to scaffolds at 200, 400 and 1200 m from the ~3 km long flight line (Fig. 1). All dosimeters at and above 17 m agl were fitted with tail vanes to align them into the wind.

SPRAY FORMULATION AND DELIVERY

An environmentally neutral aqueous fenitrothion spray simulant was developed by UNB (Picot, 1983) and the Research and Productivity Council (RPC) of N.B. (Wiesner, 1983) for these trials. In this simulant, 80% of the volume of active ingredient (AI), fenitrothion, is replaced by dibutyl phthalate and 20% by tris (2-ethyl hexyl) phosphate (TEHP). The resulting formulation, judging from the data of Tomney et al. (1978), has about the same physical properties and hence droplet size spectrum and drift potential as the aqueous fenitrothion formulation. The UAL analyzed all sampler deposits for the trapped mass of TEHP using a gas-chromatographic procedure described in Crabbe et al. (1984).

The composition of the 1983 simulant is given in table 1. Apart from the replacement of the fenitrothion, the addition of a dye to permit RPC to measure foliar deposit and slightly increased percentages of Atlox and Dowanol, the simulant has essentially the same properties as an aqueous fenitrothion formulation.

The spray formulation was atomized by TEEJETs on a single TBM spray plane flying at 77 ms^{-1} (150 kts) at ~45 m agl along the flight line. Several passes were flown in order to provide measurable quantities of TEHP on the samplers. The emission rate was 24 USGPM, or 19.61 ml per metre of flight line. Thus the line source strength used to normalize the measured droplet concentration field was $19.61 \times 0.023 = 0.45$ g m^{-1} of TEHP on the plausible assumption that all droplets had the same TEHP concentration.

METEOROLOGICAL MEASUREMENTS

Forest Protection Limited (FPL) of N.B., who supported the investigation financially and logistically, raised a 46 m meteorological tower at 400 m from the flight line to permit the UAL to profile the mean wind speed and turbulence with MRI vector vanes during the spray trials in order to compute windborne droplet transport at 24, 30 and 46 m agl. Equivalent data from Gill UVW anemometers was measured below 24 m agl by the Atmospheric Environment Service (AES) from a 30 m mast and three 17 m masts to 175 m from the flight line (Mickle, 1983), and above 46 m agl by the University of New Brunswick (UNB) using a minisonde (Steeves, 1983) at a site slightly upwind of the spray line. Wind profile data from all three groups was employed for drift computations above the forest on the basis of horizontal homogeneity of the wind field. However, the UAL averaged the AES time-mean wind profiles in the canopy flow, where large point-to-point variations were noted, when computing the wind drift below tree height.

The thermal stability of the boundary layer flow was determined from tower measurements of the ambient temperature difference between 24 and 46 m agl using MRI matched thermistors. In addition, both AES and UAL co-located micro bead thermistors with anemometry to measure the turbulent sensible heat flux. Use of these data together with the measured turbulent shear stress provided independent assessment of thermal stability in terms of the Monin-Obukhov length, L. The thermal stability and turbulent structure of the atmospheric surface layer during the spray trials is given in the Appendix.

FIELD RESULTS

The UAL conducted five spray trials during the 1983 field experiment in N.B. The mean aircraft spray height agl was measured by UNB (Picot, 1983) as follows: Trial 1, 33m; Trial 2, 41 m; Trial 3, 51 m; Trial 4, 52 m; Trial 5, 44 m. The meteorology and climatology pertinent to the experiment is given in the Appendix. A summary of the field results is given in the subsections which follow.

The droplet dosages measured by the blimp dosimeters are corrected to isokinetic sampling for use in the analysis below.

The method used is due to Fuchs (1975)* and applies more to thin-walled sampling tubes with a sharpened lip rather than to the relatively thick-walled glass adsorber tube with rounded lip used in the N.B. study. However, during a recent series of tests of a prototype atomizer in the NRC VTOL wind tunnel, the UAL compared the intake efficiency of this tube to that of one fitted with a sharpened intake adaptor. The investigation revealed that the configuration used in the N.B. study trapped only six percent more atomized material than the modified tube, probably due to flow stagnation on the rounded lip. Consequently, Fuchs' analysis was considered to be applicable to the UAL samplers after their readings were first reduced by six percent.

To convert the resulting dosages to isokinetic values, an intake efficiency, or aspiration coefficient, was computed for each droplet size interval in the spectrum measured by UNB with Rotorods at the 400 m station at mid-canopy height (Kristmanson, 1983). (The 400 m station size spectra were assumed to be representative of the 200, 400 and 1200 m station size spectra; the UNB data showed little change from 200 to 400 m or from near ground level to mid-canopy). A single value weighted over the whole spectrum was then derived for each adsorber sample and applied to the previously corrected dosimeter readings. This reduced these values by as much as 93% in the relatively high wind speed trial (No. 4), although the average reduction over all trials was only 63%. These isokinetic dosages were then used in the wind drift computations which follow.

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*Fuchs misquotes the results of Belyaev and Levin (1974). His equation (2) for the aspiration coefficient, A, should read

$$A = 1 + (\omega^{-1}-1)f(\omega,\text{Stokes number})$$

where ω is the ratio of the sampling tube intake velocity to the mean wind speed and f is defined in Fuchs' paper.

Fractional Wind Drift

The fractional wind drift is the fraction of active ingredient (AI) still in the atmosphere at successive downwind stations. At each blimp station, one set of corrected blimp dosimeter readings and the average of up to five sets of corrected canopy dosimeter readings were used in the computation for each trial. The fractional drift is given by:

$$\text{Fractional wind drift} = \int_0^h U(z) \left(\int_0^\infty C(x,z,t)dt\right) \cos\theta(z)dz/q \cos\theta(z_s)$$

where $U(z)$ = mean wind speed

C = droplet concentration

q = line source strength

θ = angle between mean wind direction and the normal to the spray line, and x, z, and t are distances along the normal, height agl and time respectively. h denotes the drift cloud top and z_s is the spraying height agl.

In the drift table (Table 2), the mean wind speed and direction at 46 m agl, U(46), stability classification and the estimated turbulent transfer velocity of drifting droplets into the canopy flow from above v_d, are included from the Appendix. In a given stability state, the latter scales with wind speed. For this reason, the budget results should be compared among trials having the same mean wind speed, but different stability. Thus, between Trials 1 and 5, there is about six times as much spray AI still in the atmosphere at 1200 m in the very stable conditions of Trial No. 5 as in the slightly unstable conditions of Trial No. 1 where there was weak convective activity in a shallow ground-based mixing layer. This difference is attributed to the presence of turbulent transfer in Trial No. 1 as expressed by $v_d = 6.6 \text{ cm s}^{-1}$, which includes the effects of mechanical turbulence as well as of the discrete thermal updrafts and return flow, and the absence of turbulent transfer in Trial No. 5. The near field drift cloud mass in Trial No. 5 is also much larger due mainly to the positive buoyancy forces acting on the vortex wake of the spray plane, which were absent, or slightly negative in Trial No. 1, although the higher spraying altitude would also have some effect in raising the near field wind drift percentages relative to those in Trial No. 1. Overall, however, these results illustrate the importance of atmospheric turbulence in transferring windborne spray material into the canopy and the advisability of avoiding ULV applications in very stable conditions.

The other two trials having nearly the same mean wind speed but different stability conditions are Nos. 3 and 4. The surface layer flow of the former was slightly stable with about one third of the turbulence intensities of the latter (see the Appendix), which was neutral resulting in about one third of the turbulent transfer velocity. As a result, the drift cloud mass was everywhere larger. Not unexpectedly, Trial No. 4, with the largest turbulent transfer velocity, had also the smallest far-field drift cloud mass.

The above result is a further example of the beneficial effect of atmospheric turbulence in enhancing ULV droplet deposition and suppressing off-target drift. In addition, its suggests that in near-neutral conditions, i.e., negligible heat flux and moderate wind speeds, the presently observed rate of decrease in the drift cloud mass with distance from the spray line would continue to be the same at higher wind speed inasmuch as the mean slope of the ULV droplet trajectories is approximately defined by v_d/U which remains essentially invariant with wind speed. Field trials in N.B. planned for 1984 will examine this hypothesis which, if valid, will greatly enlarge the daily spraying window.

In Trials No. 1 and 2, there is a slight contradiction between the airborne drift data at 200 and 400 m. This inconsistency reflects the larger problem of the difficulty of determining the volume flows through the blimp dosimeter absorber tubes under field conditions. The resulting uncertainty in these flows, ~20%, together with a further estimated 20% from other sources including uncertainty in the validity of the cubic spline interpolations used between widely spaced data points as well as errors in the values of mean wind speed and isokinetic corrections used in the analysis, places a maximum error on the tabulated drift results of about 40%. Steps are underway to reduce the overall uncertainty in field data in future investigations.

Droplet Size Distributions in the Drift Clouds

The UAL measured the size spectrum of drift cloud droplets with cascade impactors. The results are shown in Table 3 in six intervals corresponding to six impactor stages. To obtain the number of droplets, n_k, in size class k from the plate deposits m_i, the following equations are solved:

$$e_{ik} \bar{D}_k^3 \prod_{j=1}^{i-1} (1 - e_{jk}) n_k = 6m_i/\pi\rho_d$$

where e_{ik} is the impaction efficiency of droplets of diameter $\bar{D}_k$ on the ith collection plate and ρ_d is the droplet density. The overbar denotes a diameter weighted according to the following formula:

$$\bar{D}_k = \{(D_+^2 + D_-^2)(D_+ + D_-)/4\}^{1/3}$$

where '+' and '-' denote the upper and lower boundaries of size class k. The e_{ik} are drawn from numerical solutions of Laplaces equation for the air flow through the impactor and the equations of motion of the droplets. Details are given in Crabbe (1984).

In the Table 3, entries for each size class are the percent of total number of droplets captured. The UAL data are abstracted from the computer conversion of plate deposits to droplet numbers; the RPC data are interpolated from the droplet number spectra on foliage measured by Weisner (1983). The upper bound of a size class is the diameter of the droplet having 50% impaction efficiency on a stage collection plate (D_{50}); the lower bound is the value of D_{50} of the preceding stage except for the first size class where it is zero. The use of these values is predicated by the rate of change of impaction efficiency with droplet diameter having a maximum at D_{50}. No comparison is drawn between UAL and RPC data for Trial Nos. 2 and 3. The computer solution did not converge in the case of Trial No. 3 and RPC did not size their foliar droplet deposits in Trial No. 2. Both the RPC and UAL data are average values in the near field; judging from the UNB Rotorod data, little change in number spectra with distance from the spray line occurs in the near field.

The overall trend of the tabulated data is for the RPC foliar deposit numbers to be larger for those droplet sizes where the UAL drift cloud numbers are small, than for those sizes where the drift cloud numbers are large. This result is attributed to the foliar deposit being size selective; droplets smaller than about 15 µm diameter, which appear in large numbers in the drift cloud, have impaction efficiencies which are too low to justify their inclusion in the droplet spray spectrum.

The UAL also deployed cascade impactors at 1200 and 3000 m. However their plate deposits have not yet been converted to droplet diameters.

CONCLUSIONS

The following conclusions arise from the 1983 field study in N.B.:

(a) The meteorological conditions favouring complete deposition of ULV spray emissions within one km of the flight line are turbulent mixing layers produced by thermally neutral (adiabatic) temperature stratification. These conditions occur on windy, overcast to mostly overcast days. An argument based on the assumption that the chief mechanism for the downward transport of ULV droplets onto the canopy is atmospheric turbulence rather than sedimentation suggests this conclusion will continue to be valid at higher wind speeds than occurred in the 1983 neutral trial, ~6 ms^{-1} at 50 m agl. Further field study is required to confirm this hypothesis which, if valid, would greatly enlarge the daily spray 'window'.

(b) Early to mid-morning slightly unstable conditions characterized by weak convective activity (thermals) in a shallow inversion-capped mixing layer, and wind speeds at 50 m agl of about 3 ms^{-1}, also favour complete spray deposit in the first km, although the near field deposition is less than in neutral flow due to random lofting of spray droplets by thermals. However, the return flow from the thermals ensures almost complete deposit by one km when the inversion base is low, ~100 m agl or less. Thus, ~3% of the AI remained in the atmosphere at 1200 m in the slightly unstable trial compared to ~2% in the neutral trial although the airborne fraction at 400 m was 42% compared to 5% in the neutral trial. More field study is required to determine whether 'complete deposit by one km' would also occur when the inversion base is higher than ~100 m.

(c) ULV emissions in meteorological conditions of sufficient thermal stability to suppress turbulence, i.e., clear skies overnight and light winds produce relatively dense spray drift clouds containing significant fractions of the AI to beyond one km from the spray line. This is a result of the delayed descent of the aircraft vortex wake which contains most of the emission, because of the positive buoyancy forces acting on it, and the absence of downward turbulent transport of spray droplets drifting in the atmosphere beyond the near field. Thus, in wind speeds of about 3 ms^{-1} at 50 m agl, 50% of the AI was still in the atmosphere at 400 m and 17% at 1200 m. Higher wind speeds would exacerbate this situation and lower wind speeds would ameliorate it. However, inasmuch as 50 m wind speeds are rarely less than about 3 ms^{-1}, aerial applications of ULV formulations should be avoided in very stable conditions.

ACKNOWLEDGEMENT

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Table 1. Composition of Spray Simulant

Component	Density	% Volume	% Mass
dibutyl phthalate	0.99	9.3	9.0
tris (2-ethyl hexyl) phosphate	0.88	2.6	2.3
Atlox	0.98	2.6	2.5
Dowanol	0.94	2.6	2.5
water inluding 0.75% by mass Rhodamine B dye	1.0	82.9	83.7

Table 2. Windborne Spray Drift

Trial	Time (ADT)	Classification	$v_d(24)$ ($cm\ s^{-1}$)	Percent Drift 200 m	Percent Drift 400 m	Percent Drift 1200 m	U(46) (ms^{-1}/Deg
1	0825h	slightly unstable	6.6	38	42	~3	2.9/27
2	0712h	slightly stable	2.5	14	17	5	3.9/25
3	2023h	slightly stable	2.7	15	7	3	5.2/23
4	0619h	neutral	8.4	7	5	~2	5.5/19
5	0635h	very stable	~0	55	50	17	3.3/25

Table 3. Drift Cloud (UAL) and Deposit (RPC) Size Spectra (%)

Trial:	1		4		5	
Diameter Interval(μm)	UAL	RPC	UAL	RPC	UAL	RPC
0-11	64	38	84	24.5	69	16.5
11-20	22	37	11	36	17	32.0
20-29	8	20	1.5	23.5	4	33.0
29-37	3	3	2	9	6	7.0
37-47	2	1.5	1	3.5	2	6.0
47-110	1	0.5	0.5	3.5	2	5.5

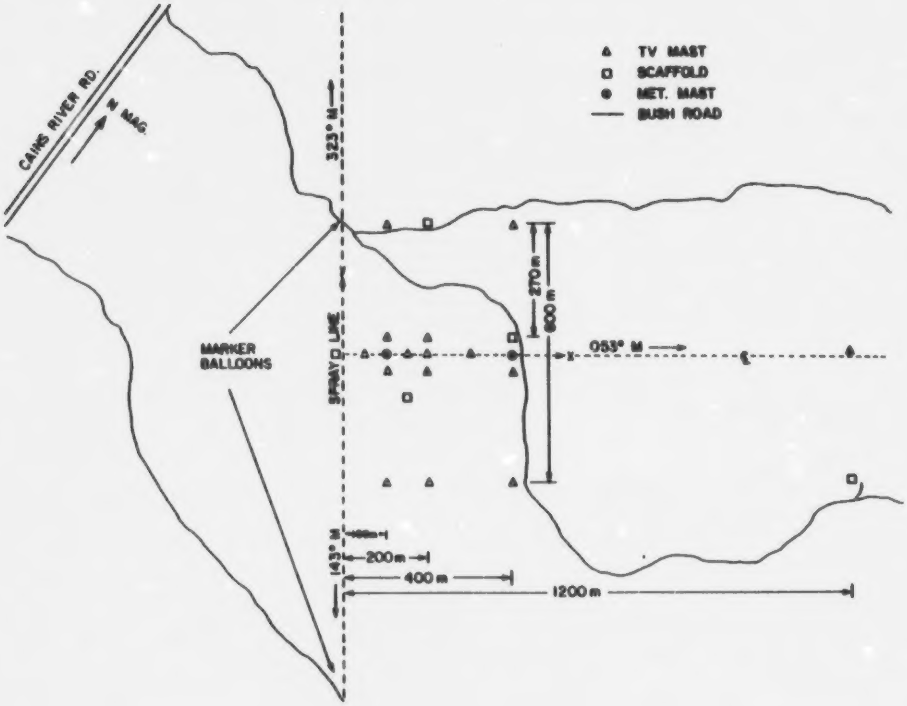
CAINS RIVER RD.
N MAG.
323° M
TV MAST
SCAFFOLD
MET. MAST
BUSH ROAD
MARKER BALLOONS
SPRAY LINE
270 m
600 m
053° M
143° M
100m
200 m
400 m
1200 m

Figure 1. Schematic of Sampling Grid.

APPENDIX

Climatic parameters and line source strengths for the five 1983 spray trials are given below:

Trial	Date	Time (ADT)	Sunrise	Sunset	No. Spray Passes	Total Release (g TEHP m^{-1})
1	22 June	0825	0530	2120	3	1.35
2	23 June	0712	0530	2120	2	0.90
3	23 June	2023	0530	2120	3	1.35
4	27 June	0619	0532	2121	2	0.90
5	29 June	0635	0533	2121	3	1.35

~ 15-min averages of ostensible meteorological parameters were as follows:

	Wind Speed (m/s)/ Direction (°M)						
Trial	24 m agl	46 m agl	T(10) (°C)	RH(10)* (°%)	T(24) (°C)	T(46)-T(24) (°C)	Classification
1	1.55/281	2.92/275	24.0	55	19.9	-0.56	Slightly unstable
2	2.16/246	3.90/255	19.4	71	17.9	0.098	Slightly stable
3	3.23/223	5.23/235	27.2	69	30.5	0.26	Slightly stable
4	3.55/195	5.55/191	12.3	74	10.1	-0.18	Neutral
5	1.47/222**	3.28/258	4.6**	~90**	4.5	1.93	Very stable

16-min averages of turbulence measured from the UAL 46 m mast are tabulated below. A linear trend was removed from the data before computing variances and fluxes. In the table, $u_* = (\overline{uw^2} + \overline{vw^2})^{1/4}$, $H = \rho c_p \overline{wT}$, $v_d = 0.7\, u_*^2 / U$ and the units are cm s^{-1} except where noted. All averages start at spray time.

Trial								
Trial	$u_*(24)$	$u_*(46)$	$\sigma_w(24)$	$\sigma_w(46)$	H(watts m^{-2})	L(m)	$R_i(32)$	$v_d(24)$
1	38.1	28.6	40.7	37.3	60	-96	-0.12	6.6
2	27.8	24.9	35.0	35.8	-17**	130	0.071	2.5
3	35.2	31.2	50.2	40.7	-38**	120	0.078	2.7
4	65.2	64.3	77.4	77.8	-0.9**	3×10^4	0.007	8.4
5	-	-	-	-	-	-	0.67	-

There are no entries for Trial No. 5; the computed value of R_i exceeds the critical value, ~0.25, for suppression of turbulence. R_i is computed from measured values of U(24), U(46), T(24) and T(46), and is valid at $z = \sqrt{(24-d)(46-d)} + d = 32$ m agl where $d = 11$ m is the displacement height of the forest. L is the Monin-Obuklov length computed from measured values of H and u_*. The reader is referred to Crabbe et al (1983) for details.

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*Based on values of wet and dry bulbs temperatures measured by UNB Dept. of Chemical Engineering.

**AES data from their 30 m mast for wind speed at 23 m and heat flux (H) at 29 m.

Poster Paper No. 10

AERIAL DEPOSITION OF THE SYNTHETIC PYRETHROID DELTAMETHRIN

Bernard D. Hill
Research Station, Agriculture Canada
Lethbridge, Alberta T1J 4B1

and

Scott Kinniburgh
Kinniburgh Spray Service Ltd.
Purple Springs, Alberta
TOK 1X0

ABSTRACT

Deltamethrin is an insecticide recently registered for the control of flea beetles in canola and mustard, grasshoppers in wheat and barley, Colorado potato beetles in potatoes, and sunflower beetles in sunflowers. It also has the potential to control cutworms in cereals, and weevil and lygus in alfalfa. Scientists at the Lethbridge Research Station have been evaluating the efficacy and residue persistence of deltamethrin since 1979.

At present, there is considerable interest in the feasibility of applying deltamethrin by air. Deltamethrin is not currently registered for aerial application. One of the prime considerations is how much deltamethrin will be deposited 'on-target' in a typical aerial application? From an agricultural use viewpoint, a high degree of deposition is required for efficacy (benefit). From an environmental viewpoint, a lack of 'on-target' deposition is potentially dangerous (risk).

This paper describes two experiments in which the amount of deltamethrin contacting the soil surface of the target area was determined. The insecticide was aerially applied in a manner representative of a commercial operation and the deposition determined by residue analysis of the soil. Plant material was not sampled because of the early crop stage and the small ratio of crop/soil surface area.

EXPERIMENTAL

1982 Experiment. On June 2, near Taber, Alberta, Decis 2.5 EC was applied to sugar beets at the 2-3 leaf stage to control flea beetles. A Pawnee PA 25-235 aircraft applied the deltamethrin at 10.7 g/ha using a volume of 9.35 L/ha. The hydraulic spray system was equpped with T-Jet 4664 nozzles and the spray parameters were adjusted to produce medium-sized droplets (100-500 μ dia.). The plane sprayed from a height of 3 m with a ground speed of 145 km/h. The weather conditions at the time of application (7:30 a.m.) were: sunny, wind SE at 10.2 km/h, relative humidity 72%, temperature 11.5°C at 3.0 m and 14.0°C at 0.01 m (slight lapse condition).

Two hours after application, composite soil samples (0-2.5 cm) were taken in duplicate from each of the four 20 × 20 m replicates. Each composite sample contained 32 soil cores (2.36 cm dia.) taken from 16 random sites (different random sites for each composite). The soil samples were analyzed for deltamethrin using a previously reported ^{63}Ni-GLC method (Hill, 1983). The soil results are reported without adjustment for the 92.5% mean method recovery.

1983 Experiment. On June 13, 20 km southeast of Taber, Alberta, Decis 5.0 EC was applied to mustard at the 2-leaf stage to control flea beetles. A Grumman Ag Cat 164 applied the deltamethrin at 7.2 g/ha using a volume of 8.88 L/ha. The hydraulic spray system was equipped with T-Jet 4664 nozzles and the spray parameters were adjusted to produce medium-sized droplets. The plane sprayed from a height of 3 m with a ground speed of

145 km/h. The weather conditions at the time of application (9:30 a.m.) were: 20% cloud cover, wind WNW at 24.0 km/h, relative humidity 52%, temperature 15.1°C at 3.0 m and 17.2°C at 0.01 m (slight lapse condition).

Two hours after application, composite soil samples were taken from 6 replicates (as previously described, but only 1 composite/replicate). The soil was analyzed for deltamethrin per the 1982 experiment.

To survey the amount of spray drift, six Teflon plates were placed 0-200 m downwind of the test site. The Teflon plates were extracted with hexane and the extract analyzed directly by ^{63}Ni-GLC. The Teflon results are reported without adjustment for the 98.7% mean method recovery.

RESULTS AND DISCUSSION

1982 Experiment. The plane applied the deltamethrin in a north-south direction and laid down successive spray swaths from west to east into the prevailing wind (Fig. 1). The weather conditions at the time of application were considered ideal. The mean values (of the duplicate composite samples) for the amount of deltamethrin deposited in each replicate were 35, 62, 65 and 28% of the 10.7 g/ha application rate. There was excellent agreement between the duplicate composite samples (σ_c = 7.9% of applied) indicating that 16 sites and 2 cores/site gave a representative composite sample. The deposition was lighter near the ends of the spray passes (Fig. 1). There was a highway adjacent to the south end of the field and a pasture at the north end which necessitated the plane 'dropping into' the sugar-beet field as it commenced spraying. The amount of 'end effect' indicates that the height and attitude of the plane had a critical effect on deposition. In a commercial operation, the ends would have been re-sprayed in an east-west direction to ensure insect control, but this was not requested in this experiment.

1983 Experiment. The plane applied the deltamethrin in a north-south direction and laid down successive swaths from east to west into the prevailing wind (Fig. 2). The weather conditions at the time of application were not ideal (wind >20 km/h and relative humidity <60%). To allow for the wind (normal practice), the plane began spraying one swath width inside the east edge of the field and finished one swath width outside the west edge of the field. The amount of deltamethrin deposited on the soil was 70, 76, 70, 74, 79, and 67% of the 7.2 g/ha application rate. The deposition was very uniform within the treated area. There was ample room beyond the north-south ends of the field for the plane to achieve the proper height and attitude before commencement of spraying. No real 'end effect' was observed.

Teflon plates had been placed 50, 100, and 200 m downwind of the treated area to survey the amount of drift (Fig. 2). The deposition on these drift plates (0.2 - 2.3% of applied) was extremely low considering the 24 km/h wind.

General Discussion. Two completely different spray operations are described in this paper. In the 1982 experiment, under 'ideal' conditions, the mean deposition was 64% of applied deltamethrin (neglecting the 'end effects'). In the 1983 experiment, under less than 'ideal' conditions, the mean deposition was 73% of applied. This contradiction serves to emphasize that every spray operation is unique and one must use caution in extrapolating these results to proposed spray operations. Although difficult to obtain, accurate droplet size data would have greatly aided the comparison of the two spray operations.

Deposition of 64 and 73% implies there was 36 and 27% drift, however, the deposition data was not corrected for the 92.5% mean recovery of the residue analysis method or for losses during sampling. Allowing a maximum of 15% for sampling and residue method losses, leaves 21 and 12% of applied as potential drift. In a previous experiment where a tractor-mounted plot sprayer was used to apply deltamethrin, there was 68% deposition, and allowing 15% for sampling and method losses, left 17% as potential drift (Hill, unpublished). The term potential drift is actually 'unexplained loss' and is comprised of droplet drift, evaporation, and deltamethrin 'dust' suspended in the air. It is incorrect to assume that all of the 'unexplained loss' is drift that will be deposited downwind. In the 1983 aerial experiment with 12% potential drift, the drift plate data indicate that on average only 1.2% of applied deltamethrin was deposited within the 0-200 m downwind area.

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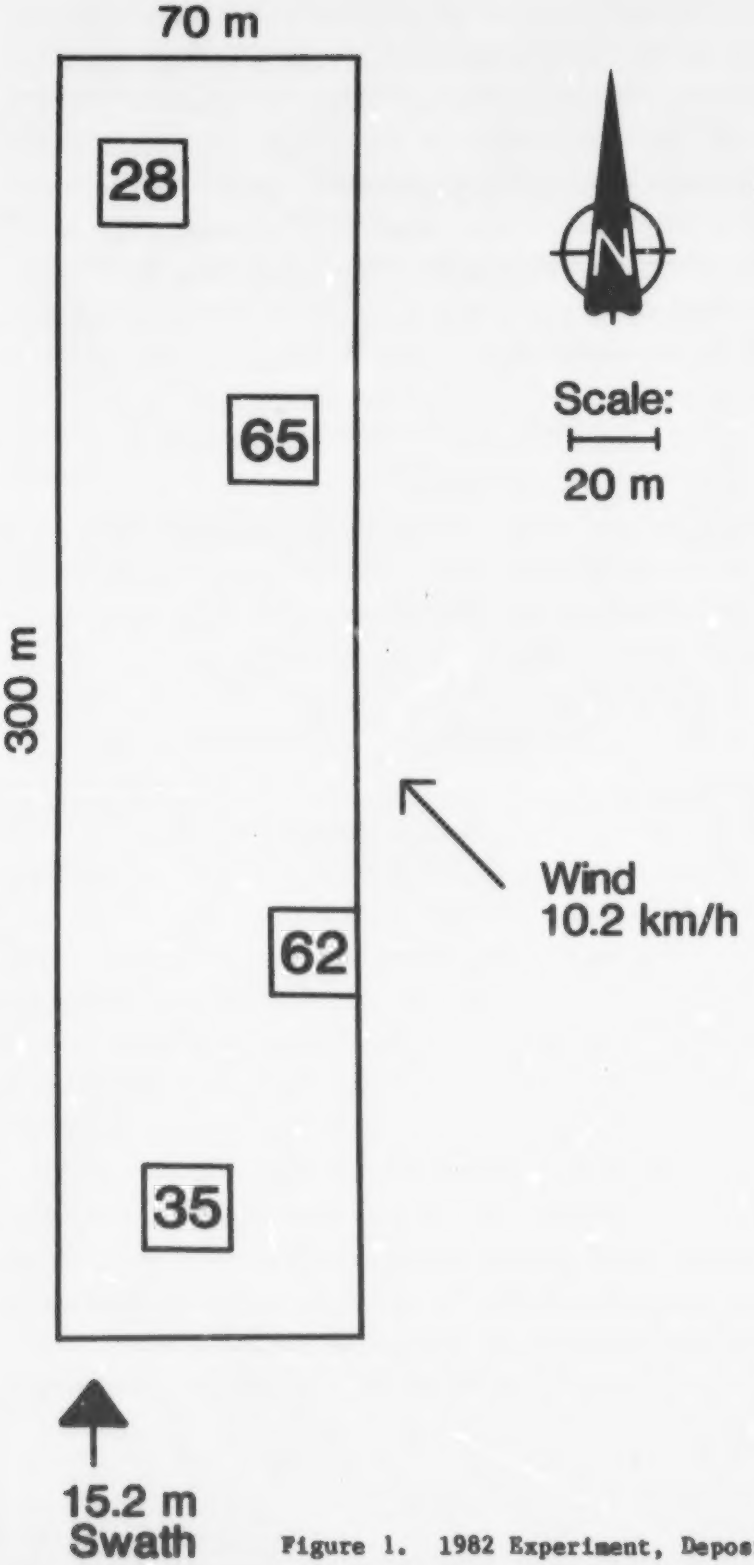
70 m
300 m
28
65
62
35
N
Scale:
20 m
Wind
10.2 km/h
15.2 m
Swath

Figure 1. 1982 Experiment, Deposition (% of applied).

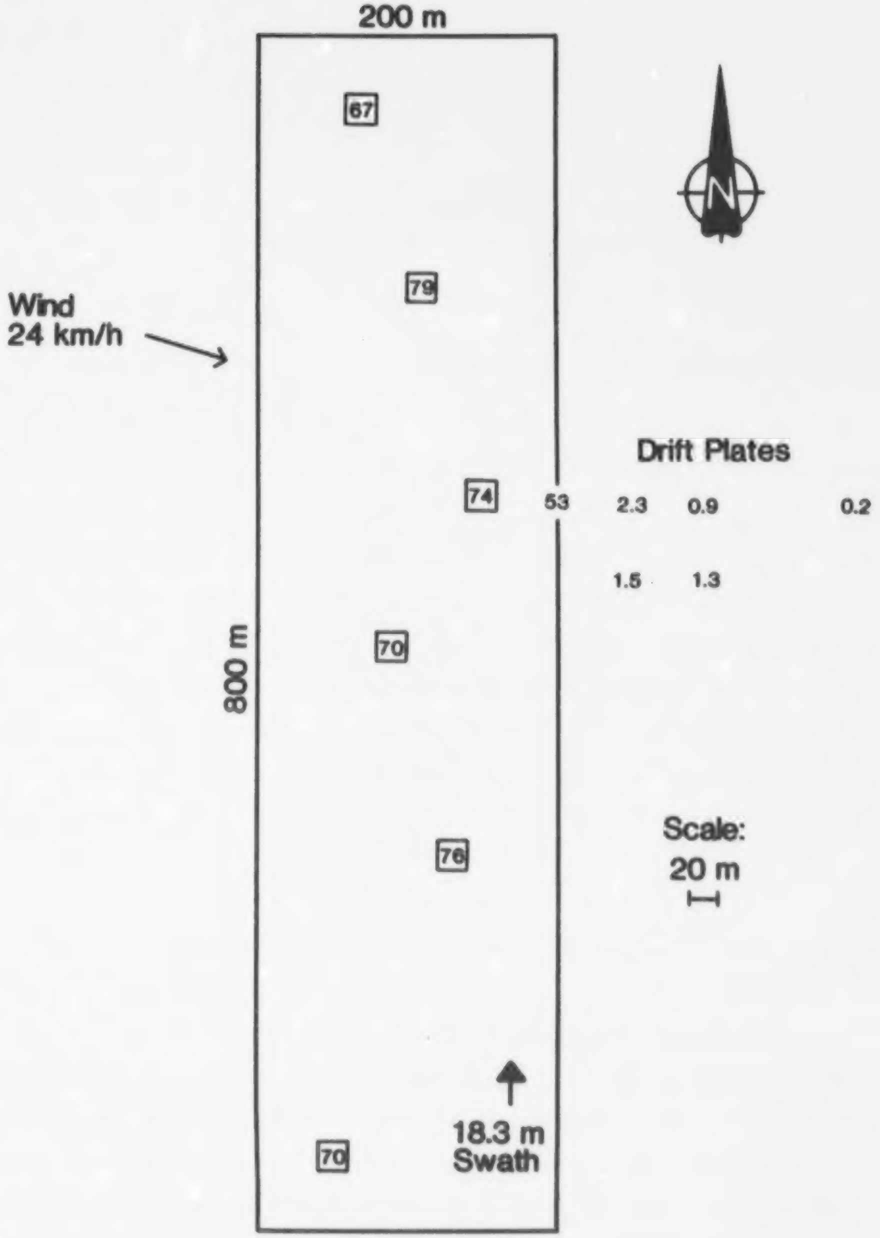
200 m
800 m
67
79
74
70
76
70
Wind
24 km/h
N
Drift Plates
53
2.3
0.9
0.2
1.5
1.3
Scale:
20 m
18.3 m
Swath

Figure 2. 1983 Experiment, Deposition (% of applied).

Poster Paper No. 11

THE CHANGING PRAIRIE CLIMATE: PROBLEM OR OPPORTUNITY?

H.M. Fraser
Regional Chief, Scientific Services
Atmospheric Environment Service
Winnipeg, Manitoba
R3C 3V4

ABSTRACT

Carbon dixoide levels in the atmosphere are increasing due to the combustion of fossil fuels. This will inhibit the escape of heat from the earth, and by the middle of the next century, Prairie summers could be 3°C warmer and winters 5°C milder. The effect on moisture is complex to predict but some drying is possible in southern areas. The effects on present day agriculture will be mixed, but the opportunity exists to adjust in anticipation of a changing climate.

PALEOCLIMATOLOGY

Paleoclimtology allows us to look back a remarkable distance in time, it is estimated for example that there have been twenty-three major ice ages at very approximate intervals of 100,000 years. Figure 1 is an estimate of temperatures in four world areas during the last 100,000 years as implied from various sources. The agreement is clear as one sees the broad shape of the most recent ice age. Figure 2 illustrates the most recent 10,000 years which would include recorded history. Temperatures now appear to be similar to those at the time of the birth of Christ and in between is a cold period often referred to as the "little ice age".

Closer to home, Figure 3 is a composite trend of temperatures and precipitation at Regina, Saskatoon and Winnipeg since 1900, except that the period 1880 to 1890 is represented by Winnipeg alone. Ten year running means are used. Apparent is the rise in temperature of over 2°C from the beginning of the period to the 1930's; and an overall decline of 1°C from then until the early 70's. The magnitude and rate of these temperature changes is important for they form a basis for comparison with future estimations. Also clear from the graph is the inverse correlation of precipitation with temperature.

THE CAUSES OF CLIMATE CHANGE

All of the energy to drive the earth's weather systems comes from the sun. Any variation in the sun's output, in the ability of the atmosphere to transmit that energy, or of the earth to absorb it, could alter the climate. Theories abound on these variations.

"Sunspots" may represent variations in solar output. Although specific measurement or theory relating energy reaching the earth to these transitory effects on the sun surface has been lacking (Landsberg, 1982), the cyclic nature of sun spots is temptingly regular. Many researchers have noted that the apparent correlation between severe and variable weather and the "double sunspot cycle" of 22 years; the climatic extremes of the 30's, the 50's and the 70's are often cited as evidence.

One of the powerful theories is that originated by Milankovich in the 1920's and further developed by others, including Imbrie and Imbrie (1979). Sometimes referred to as the "stretch, wobble and roll" theory, it propounds that variations in the earth's axis of rotation and the shape of its revolution affect its distance from and aspect to the sun. The ability to make the necessary astronomical calculations far back in time facilitated its development.

Particles in the atmosphere reflect, or absorb and re-radiate some solar energy before it reaches the earth. This material includes windblown sand, dust, sea salt, smoke and volcanic debris. The last is the basis for another popular theory which relates aberrations in the climate to volcanic activity; it claims some support from apparent specific effects of history's more massive eruptions.

The earth itself is not entirely receptive to solar energy. It is estimated that 30% of incoming solar radiation is reflected by the earth's surface and changes in albedo caused by variations in ice and snow cover, deforestation, cultivation, desertification, etc. result in significant changes in the energy balance.

The foregoing theories have been presented in barest outline here and represent only the most common and most plausible of many speculations. They also represent natural processes and could almost without exception occur if man did not inhabit the earth; but man is not without his part in this affair. Every year we hurl deliberately or carelessly hundreds of million of waste particles and gases into the atmosphere.

The threat from gases is more serious in the present perception. Gaseous wastes from anthropogenic sources may not be greater than that from nature but are enough to cause an overloading, to total more than can be cycled harmlessly through the atmosphere. Emissions of sulphur dioxide and other oxides are leading to acid rain, which, if not global in extent, is a very serious regional problem. A second and possible more ominous manifestation is the atmospheric buildup of carbon dioxide.

The records of atmospheric carbon dioxide are scattered and short; the best is that from Mauna Loa, Hawaii, since 1958 and it is shown along with other readings on Figure 4. The agreement is striking. Every available record demonstrates similar levels and a similar trend, indisputable evidence that the atmospheric concentration of carbon dioxide is rising. Processes, natural and man made, have been adding carbon dioxide at an increasing rate, which is now 3-4% per decade. The principal source is the burning of fossil fuels.

The mounting concentration of this gas is alarming because of the "greenhouse" effect. Radiation from the sun is of a short wave length and passes through the carbon dioxide in the atmosphere toward the earth; but counter radiation from the earth and clouds is of a much longer wave length and is impeded by carbon dioxide. The effect is reminiscent of a greenhouse (though it is not an apt analogy) preventing the escape of some of the earth's heat and resulting in a gradual warming.

A quantitative forecast of warming due to increasing carbon dioxide has been the object of intense climate research and the most convincing answers are those offered by simulations of the atmosphere referred to as global circulation models. Figure 5 represents the warming estimated by a number of these models for a doubling of CO_2 from pre-1900 levels (Hare, 1979). Although there is considerable variation in the degree of warming predicted, there is clearly a concentration toward 3°C. In assessing the possibilities, the National Academy of Sciences of the U.S.A. in 1979 estimated the equilibrium global surface warming from a doubling of CO_2 to be "near 3°C with a probable error of ± 1.5°C"; and in 1982 the National Research Council (U.S.) concluded that "no substantial revision of this conclusion is warranted at this time".

It is also likely that the effect is being increased by other trace gases. Oxide of nitrogen, chlorofluoromethanes, hydrocarbons and carbon monoxide by themselves or thorugh photochemical transformation also provide infrared absorption and may be adding as much as 50% to the carbon dioxide effect.

The time at which carbon dioxide doubling will occur is itself a point of much conjecture. The pessimistic view maintains that world trends in energy consumption will continue and that doubling will be realized in about 50 years. The optimistic view is that declining fossil fuel resources, increasing energy efficiency, alternate energies or other strategies will reduce the rate of increase and delay the doubling for at least 100 years. Recent events and attitudes, including the resurgence of coal and declining oil prices, produces some bias toward the pessimistic. All considered, an average global warming of 3°C by the year 2050 due to carbon dioxide and possible other trace gases seems plausible; this would be a world climate warmer than any since the dawn of recorded history.

A three degree warming would not be evenly distributed over the world, it would be somewhat less in the tropics and significantly higher toward the poles especially in winter. This is attributed to the positive feedback effect whereby the reduction of reflective snow and ice cover increases the solar radiation absorbed by the earth; this effect can be expected in countries with a significant snow cover season. A reasonable interpretation for the Prairies is that winters will be close to 5°C warmer than now, while summers will be nearer the 3°C average global warming.

Figures 6 and 7 display isopleths of mean monthly temperature in North America for January and July; the predicted warming is illustrated by employing five and three degree isopleths respectively. The suggestion is that the future temperature regime will resemble the present climate of the Dakotas and Montana.

We cannot be as confident regarding moisture in a warmer climate. Higher temperatures would produce more evaporation from the oceans resulting on average in more precipitation world-wide; but again distribution would be uneven. The mountain masses of western North America would continue to inhibit the spread of moisture to the interior plains and the higher temperatures of those plains would increase evaporation from the land surface. The balance between these wetter/drier factors is a critical one which the models are not precise enough to determine with confidence.

The most useful information on moisture comes from the study of the climate of the Altithermal; this has been used by Kellogg and Schware (1982) to estimate probable soil moisture patterns on a warmer earth (Figure 8). The suggestion is that the central plains of North America will have lower soil moisture and although concentrated in the U.S.A. near 45°N some effect may be felt on the Canadian prairies. We should not attempt to read precision into such predictions; we should though realize that the odds in the Prairier Provinces favour drier rather than wetter, particularly in the southwest.

In brief summary the Prairie picture which emerges for 2050 is one of summers three degrees warmer than we now know them, and winter averages five degrees higher. Soil mosture will probably be reduced in the southwest.

CLIMATE CHANGE AND MAN'S ACTIVITIES

Canada's climate is one of extremes and social and economic activities have been carefully adjusted to those extremes, often pushed to the limit. The climate shift predicted would have widespread effects although not all undesirable; in fact in a land of harsh winters there is an instinctive feeling that warming would have more advantages than disadvantages. At the same time, we must focus on vital climate sensitive industries where the effect could be profound; the foremost of these is agriculture.

AGRICULTURE

As a major export industry agriculture should be set in global perspective. Referring again to Figure 8 the estimate is that most world areas presently arid will enjoy higher soil moisture in the warmer regime, hopefully increasing their food production potential. In constrast, the current bread baskets of the U.S.S.R. and North America, including the Canadian plains, will suffer a moisture decrease which will impair productivity. Carl Butzer

(1980) of the University of Chicago proposes that the net effect on world food supply would be decidedly negative and that the improved areas could not balance the losses in the productive zones. He notes that much corn acreage in the U.S.A. would shift to wheat which is of substantially lower productivity; while the shift of corn and wheat northward is limited by soil types.

Some estimates of impact now being developed by Williams (1983) suggest that on the southern prairies warming of 3°C and soil moisture reduction of 20% could reduce cereal crop yields by 10-20%. This does not, however, take into account possible adaptation by the agricultural industry.

Sylvan Wittwer (1980) of Michigan State University believes that agriculture can adapt with no loss of productivity. He cites the history of almost uninterrupted productivity increase in the face of climate trends very similar to those being predicted. The Canadian experience is similar but progress in the future may require more strenuous efforts that those in the past.

Another positive effect is that carbon dioxide is commonly a limit to photosynthesis and increased levels will enhance growth provided water, nutrients, heat and light are available. Supporting evidence for this effect is widespread as is its commercial exploitation in greenhouses; the outlook is only slightly clouded by the anticipation that for some plants initial enhancement may give way to a relapse in growth rate. Overall, Wittwer suggests that carbon dioxide enrichment could increase crop yields by as much as 20% by the end of this century if other inputs are not limiting.

An increase of mean temperature will significantly increase the length of the frost-free season; McKay and Allsopp (1981) suggest a lengthening of approximately ten days for a one degree mean temperature rise. This notable increase would be realized near the turn of century should the predicted warming occur, and on continuation the season will stretch 30 days by mid-century. A majority of the weather stations in the agricultural area of the Prairie Provinces now report frost-free seasons in excess of 90 days three years out of four; this probability could extend to 100 days by year 2000 and 120 days by 2050. As another measure of heat gain a three degree rise in summer temperature will add some 10% to the climatologically available growing degree days.

A potential disadvantage of a warmer atmosphere is an increase in agricultural pests and diseases. For example for some insects the longer and warmer season would increase the number of generations and multiply the control problem. Fortunately the record of improved control by chemical or other means is a good one and has made no small contribution to improved productivity over the years.

If soil moisture is in danger of being reduced, so then are the other components of the hydrologic cycle including ground water, runoff and storage in water bodies. Some large systems which draw mainly on non-Prairie areas, would be least affected; the Saskatchewan River with its mountain sources is one example, while Lake Winnipeg is fed mostly by the Saskatchewan and by rivers originating in northwestern Ontario. The most vulnerable areas would be those relying on local supply, including a spring freshet that would have to last through a longer, hotter summer. Livestock operations in the south and west could be those most threatened by this water supply situation.

As previously mentioned, climatic capabilities for agriculture would be shifted northward into what are now temperature limited areas. The shift is clearly limited by soil types, but there are prospects of more viable agriculture in Manitoba's Interlake, in the northern Parkland in Saskatchewan, and in large areas of Alberta including the Peace River country.

On balance there is every reason for optimism. Beneficial effects plus the demonstrated resilience of agriculture should outweigh negative features of the likely climate change. Certainly they will if the situation is recognized as a challenge and an opportunity not only to hold our own but to improve. They may not if we attempt instead to sustain the industry precisely as it is today and not seek ways to adjust.

REACTION AND ADJUSTMENT

It is the task of Climatologists to continue their earnest research into carbon dioxide and climate change until the evidence is clear and the change quantified. This may take twenty years. In the meantime, it is unrealistic to expect that there will be a massive effort to adapt agriculture or for that matter other industries in other parts of the world. If we do nothing, however, we may find ourselves in an unfavourable catch-up position. What is needed is a strategy that offers every chance of success without heavy demands on the purse. Such a strategy exists; its mainstay is selective research based on existing strengths and directed at critical climate impact areas.

Research in agrometeorology and hydrometeorology are well established on the Prairies and have impressive records of success. With even a partial redirection and modest increases in resources much can be done to put us in a more favourable position. When that is recognized some priority research areas might include the performance of plants under carbon dioxide enrichment; inhibition of evaporation through techniques such as minimum tillage; the viability of crops with greater heat requirements; expanded water storage; and water conservation.

Thrusts such as the foregoing are particularly attractive in that they will yield benefits whether or not a significant change in climate occurs. This probability exists precisely because of the long standing recognition of the relationship between climate and activities in Canada and the existence of mechanisms directed at optimizing that relationship.

SUMMARY

That the concentration of carbon dioxide is increasing cannot be doubted. The overwhelming body of scientific opinion is that it will alter world climate and the best estimates available for the Prairies are that the climate will be warmer than at present while soil moisture might well decrease particularly in the southwest. The impact on agriculture could be severe if a blind eye is turned to the possibility of such change. A program to augment existing strengths in agrometeorology and water management could be undertaken at relatively little cost and with the prospect of high pay-off; properly pursued it could place the Prairie Provinces in an advantageous position and is an opportunity which should be grasped.

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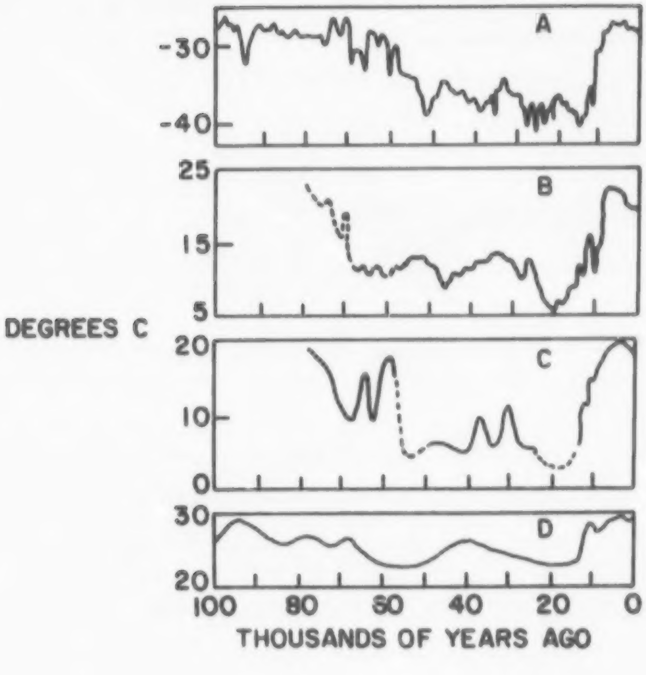

Figure 1. World Temperature Over the Past 100,000 Years (from Hare)
A. Northern Greenland - Oxygen Isotope
B. Central Europe - Pollen Analysis
C. Netherlands - Pollen Analysis
D. Tropical Atlantic - Oxygen Isotope

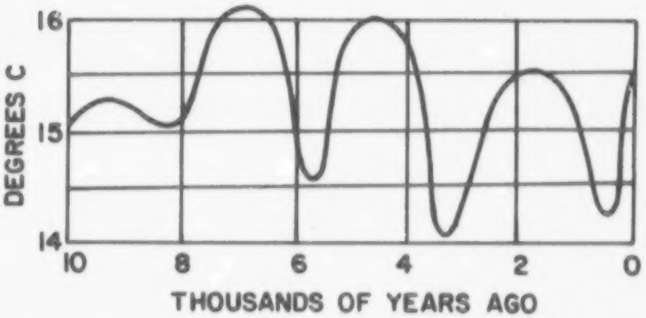

Figure 2. World Temperature over the Past 10,000 Years

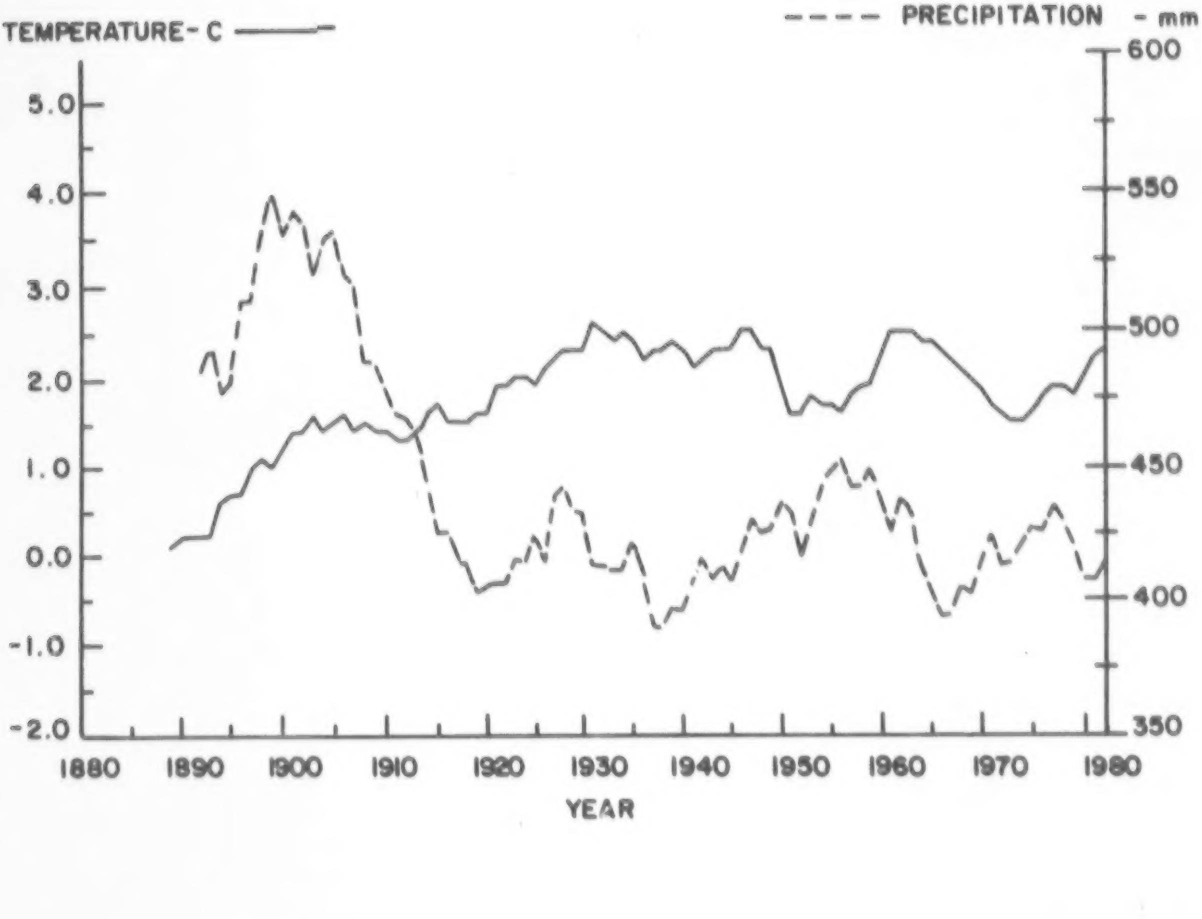

Figure 3. Climatic Conditions - Eastern Prairies 1880-1982

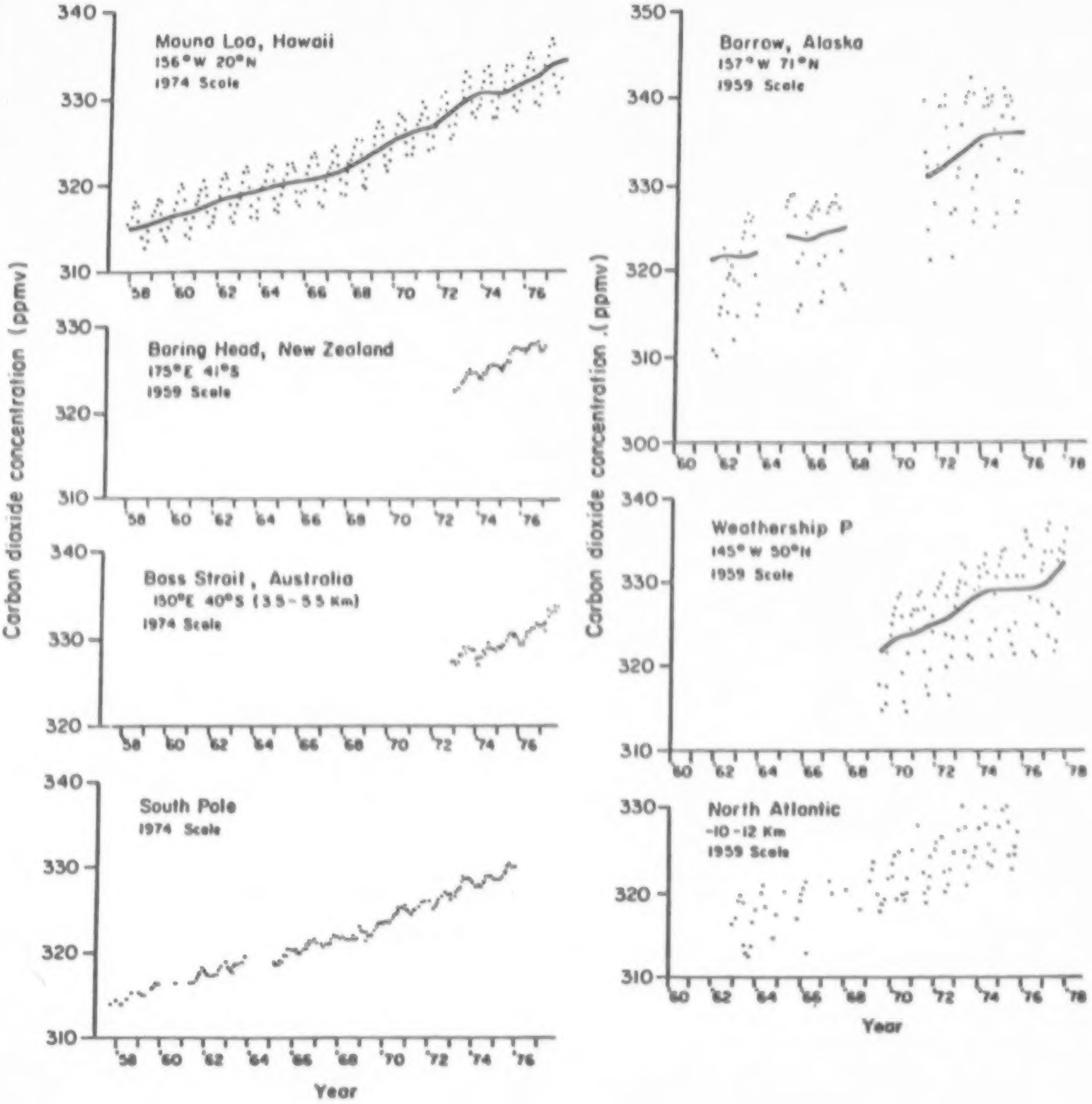

Figure 4. Trends in Concentration of Atmospheric CO_2 (from Hare).

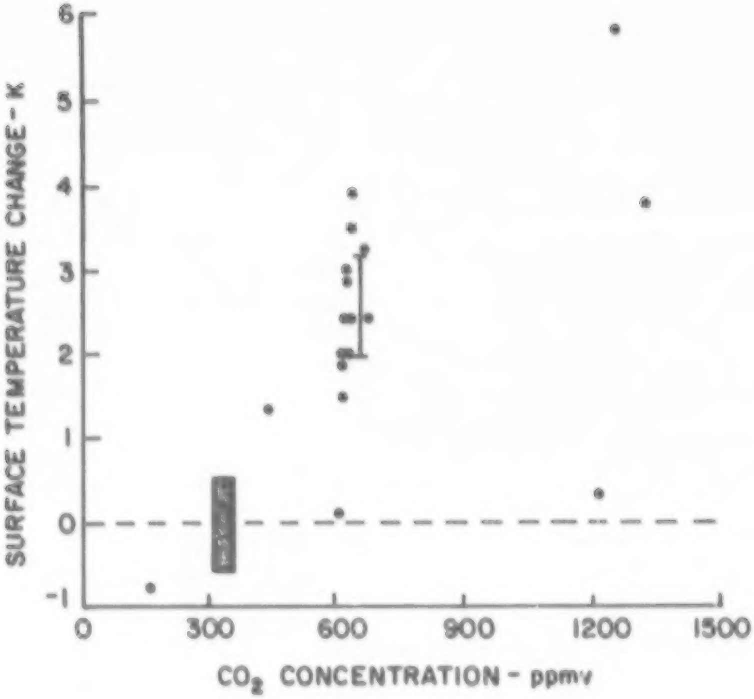

Figure 5. Model Calculations of Temperature with Various CO_2 Concentrations. (from Hare)

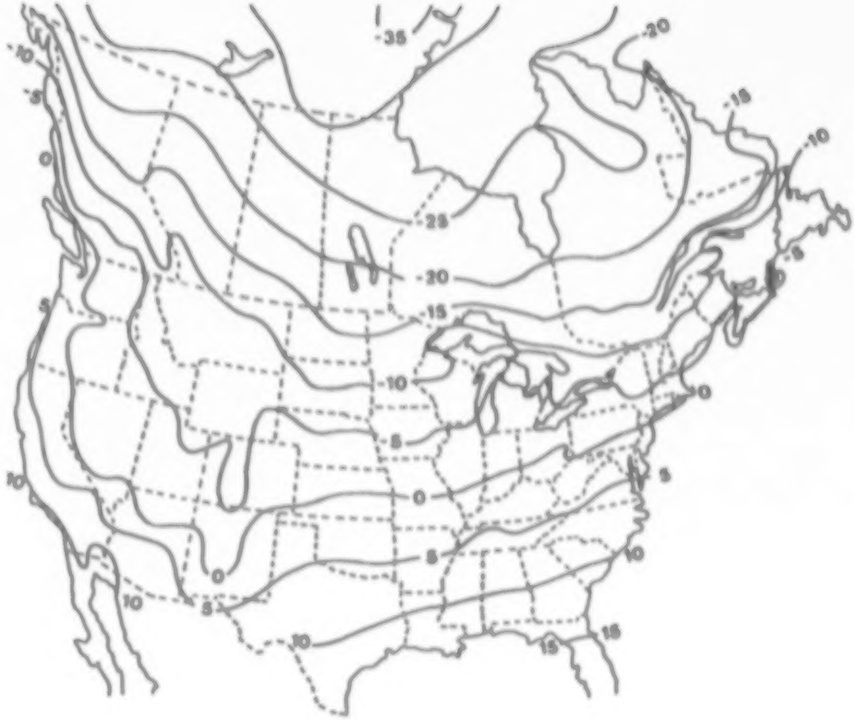
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Figure 6. Mean January Temperatures - °C, North America

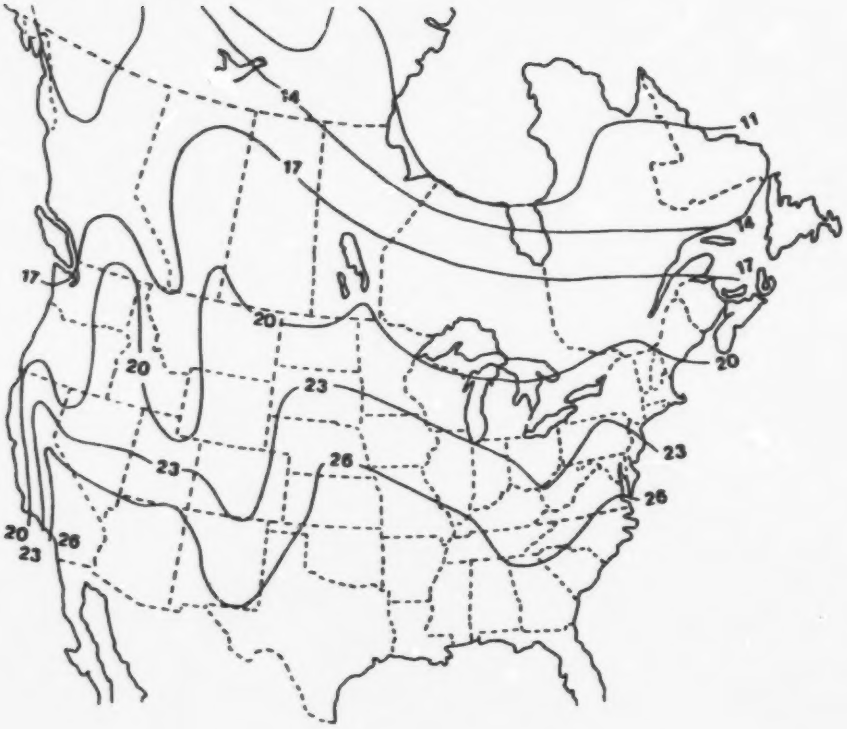
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Figure 7. Mean July Temperatures - °C, North America

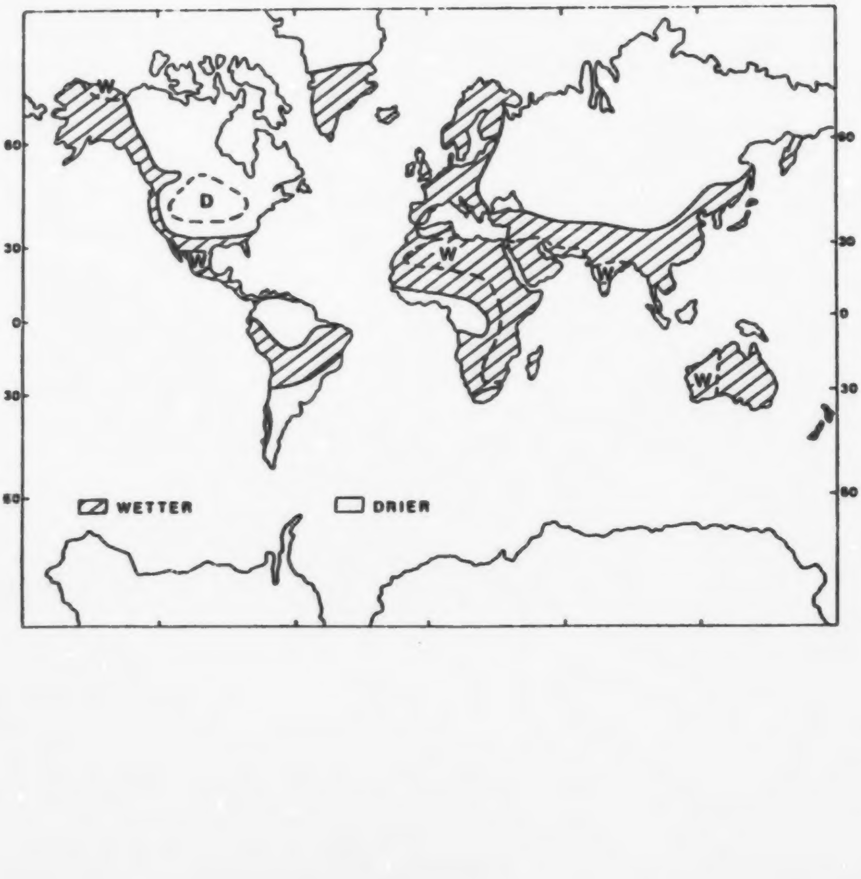
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Figure 8. Soil Moisture Patterns on a Warmer Earth (from Kellogg and Schware)

THE FUTURE ROLE OF AVIATION IN AGRICULTURE

Organizing Committee

Mr. W.C.E. Loftus
Chairman, ACAFA
P.O. Box 669
7 Edward Street
Manotick, Ontario
KOA 2NO

Dr. A.M. Drummond
Secretary, ACAFA
National Aeronautical Establishment
National Research Council of Canada
Ottawa, Ontario
K1A OR6

Dr. J. Maybank
Director, Environment Section
Saskatchewan Research Council
30 Campus Drive
Saskatoon, Saskatchewan
S7N OX1

Mr. Carl E. Lynn
Information Officer
Research Station
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan
S7N OX2

Dr. J.R. Hay
Director
Research Station
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan
S7N OX2

Mr. D. Knox
President
Assiniboia Flying Service Ltd.
Box 129
Mazenod, Saskatchewan
SOH 2YO

Mr. P.W. Voisey
Director
Engineering & Statistical
Research Institute
Research Branch
Agriculture Canada
Ottawa, Ontario
K1A OC6

The Organizing Committee is grateful for the help given in organizing and running the Symposium by:

Mrs. Martha J.K. Howey
Engineering & Statistical
Research Institute
Research Branch
Agriculture Canada
Ottawa, Ontario
K1A 0C6

Miss Gladys Hall
Research Station
Research Branch
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan
S7N 0X2

Mr. Roy Lincoln
Research Station
Research Branch
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan
S7N 0X2

These people looked after registration and visual aids, items essential for a smooth running program.

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Membership List

National Research Council Associate Committee on Agriculture and Forestry Aviation

Chairman:

Mr. W.C.E. Loftus
P.O. Box 669
7 Edward Street
Manotick, Ontario
K0A 2N0
Tel: (613) 692-2134

Secretary:

Dr. A.M. Drummond
National Aeronautical Establishment
National Research Council
Ottawa, Ontario
K1A 0R6
Tel: (613) 998-3567

Dr. C.H. Buckner
CANUSA Spruce Budworm Programme
Canadian Forestry Service
Environment Canada
Place Vincent Massey
Ottawa, Ontario
K1A 0E7
Tel: (613) 997-2175

Dr. J.G. Davidson
Energy and Resources
Dept. of Lands and Forests
175 St. John Street
Quebec City, Quebec
G1R 1N4
Tel: (418) 643-4670

Dr. R. Deboo
Director, Protection Branch
B.C. Ministry of Forests
1450 Government Street
Victoria, B.C.
V8W 3E7
Tel: (604) 387-5965

Dr. Claire A. Franklin
Chief, Pesticides Division
Environmental Health Centre
Health & Welfare Canada
Tunney's Pasture
Ottawa, Ontario K1A 0L2
Tel: (613) 593-6010

Mr. G. Gaboury
Energy and Resources
Dept. of Lands and Forests
175 rue St. Jean
Quebec City, Quebec
G1R 1N4
Tel: (418) 643-4670

Dr. G.W. Green
Canadian Forestry Service
Forest Pest Management Institute
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7
Tel: (705) 949-9461

Mr. M. Hicks
Hicks and Lawrence Ltd.
P.O. Box 519
St. Thomas, Ontario
N5P 3V6
Tel: (519) 842-8786

Mr. H.J. Irving
Managing Director
Forest Protection Ltd.
P.O. Box 1030
Fredericton, N.B.
E3B 5C3
Tel: (506) 357-3366

Mr. T. Jansen
Alpine Helicopters
165 George Craig Blvd. N.E.
Calgary International Airport
Calgary, Alberta
T2E 7H3
Tel: (403) 277-0738

Mr. D. Knox
President
Assiniboia Flying Service Ltd.
Box 129
Mazenod, Saskatchewan
SOH 2YO
Tel: (306) 354-7744

Dr. G. Lindberg
National Aeronautical Establishment
National Research Council
Bldg. M-13A, Montreal Road
Ottawa, Ontario K1A OR6
Tel: (613) 993-0141

Mr. W. Lobay
638 Romaniak Road
Edmonton, Alberta
T6R 1A6
Tel: (403) 438-6176

Mr. K.B. Marsden
Conair Aviation Ltd.
P.O. Box 220
Abbotsford, B.C. V2S 4N9
Tel: (604) 853-1171

Dr. J. Maybank
Director, Environment Section
Saskatchewan Research Council
30 Campus Drive
Saskatoon, Saskatchewan
S7N OX1
Tel: (306) 664-5417

Mr. D. Peck
Flight Services Directorate
Transport Canada
58 Service Road
Ottawa International Airport
Ottawa, Ontario K1V 9B2
Tel: (613) 998-4363

Mr. M. Pelletier
Energy and Resources
Dept. of Lands and Forests
175 rue St. Jean
Quebec City, Quebec
G1R 1N4
Tel: (418) 643-4670

Mr. M. Stewart
Pesticides Division
Food Prod. & Inspection Branch
Agriculture Canada
Ottawa, Ontario K1A OC6
Tel: (613) 995-7900

Dr. W. Varty
Maritime Forest Research Centre
Box 4000
Fredericton, New Brunswick
E3B 5P7
Tel: (506) 452-3500

Mr. P.W. Voisey
Director, Engineering and
Statistical Research Institute
Research Branch
Agriculture Canada
Ottawa, Ontario K1A OC6
Tel: (613) 995-5179

Mr. A.D. Wood
Flight Research Laboratory
National Aeronautical Establishment
National Research Council
Ottawa, Ontario K1A OR6
Tel: (613) 998-3180

LIST OF REGISTRANTS

Mr. Harvey S. Anderson
May & Baker Canada Inc.
413 Main Street
Saskatoon, Saskatchewan
S7N 0B9
Tel: (306) 244-4057

Mr. Tim Anderson
Redwing Aviation Ltd.
Box 411
Bonnyville, Alberta
T0A 0L0
Tel: (403) 826-4549

Mr. R. Arndt
Arndt Air Ltd.
405 - 3rd Avenue N.W.
Weyburn, Saskatchewan
S4H 1R2
Tel: (306) 842-4500

Mr. G.B. Atkinson
Atmospheric Environment Service
Environment Canada
Room 1000
266 Graham Avenue
Winnipeg, Manitoba
R3C 3V4
Tel: (204) 949-6059

Ms. Nusin Basak
c/o Dept. Chemical Engineering
University of New Brunswick
P.O. Box 4400
Fredericton, New Brunswick
E3B 5A3
Tel: (506) 454-9407

Mr. Gabriel Bast
Box 186
Sedley, Saskatchewan
Tel: (306) 885-2022

Mr. André Bélanger
Research Station
Agriculture Canada
P.O. Box 457
St-Jean-sur-Richelieu, Quebec
J3B 6Z8
Tel: (418) 346-4494

Mr. E. Bellay
Smith Air (1976) Ltd.
96 Belbeck Place
Swift Current, Saskatchewan
S9H 4E2
Tel: (306) 773-6441

Mr. Brian Berger
Sky Farmer Aerial Applicators Ltd.
#308, 50 Gilchrist Crescent
Red Deer, Alberta
T4P 2X6
Tel: (403) 343-8895

Mr. E. Bevan
Herschel Air Service
Box 5
Herschel, Saskatchewan
S0L 1L0
Tel: (306) 377-4507

Mr. C. Brandley
Legal Counsel
Alberta Agriculture
Agriculture Centre
Lethbridge, Alberta
T1J 4C7
Tel: (403) 329-5131

Mr. M. Brandt
Oliver Agricultural Supply
236 - 36th Street North
Lethbridge, Alberta
T1H 3Z7
Tel: (403) 328-0620

Mr. Allan Brown
Dupont of Canada
Box 2300, Streetsville
Mississauga, Ontario
L5M 2J4
Tel: (416) 821-5584

Mr. K.W. Browne
Director, Pesticides Control
Environmental Services Branch
Dept. of the Environment
P.O. Box 6000
Fredericton, N.B.
E3B 5H1

Mr. Walter Bublish
Box 463
Davidson, Saskatchewan
S0G 1A0
Tel: (306) 567-3220

Mr. Stuart Buckingham
Buckingham Ag. Services
Box 111
Aylesbury, Saskatchewan
S0G 0B0
Tel: (306) 734-2745

Dr. C.H. Buckner*
CANUSA Spruce Budworm Programme
Canadian Forestry Service
Environment Canada
Place Vincent Massey
Ottawa, Ontario
K1A 0E7
Tel: (613) 997-2175

Mr. Errol Caldwell
Program Manager for Forest Pest
Management Institute
Box 490
Sault Ste. Marie, Ontario

Mrs. Martje Campbell
Research Station
Research Branch, Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan S7N 0X2
Tel: (306) 343-8214

Research Station
Agriculture Canada
Lethbridge, Alberta
T1J 4B1
Tel: (403) 327-4561

Mr. Thane Clarke
Department of Agriculture
Province of Prince Edward Island
Box 1600
Charlottetown, PEI
C1A 7N3
Tel: (902) 892-5465

Dr. H.T.M. Colwell
Energy Analysis and Policy Division
Regional Development Branch
Agriculture Canada
Ottawa, Ontario
K1A 0C5
Tel: (613) 995-9554

Mr. W.J. Cowie
District Pesticides Officer
Central Region
Ministry of the Environment
Government of Ontario
12 Fairview Road
Barrie, Ontario L4N 4P3
Tel: (705) 726-1730

Dr. R.S. Crabbe
National Aeronautical Establishment
National Research Council
Bldg. M-10, Montreal Road
Ottawa, Ontario K1A 0R6
Tel: (613) 993-2521

Mr. Bruce Croft
303 - 502 5th Street
Weyburn, Saskatchewan
S4H 1W2
Tel: (306) 842-1675

Mr. M. Dahl
Parkside Aerial Application
Box 102
Parkside, Saskatchewan
SOJ 2A0
Tel: (306) 747-3064

Dr. J.G. Davidson
Energy and Resources
Dept. of Lands and Forests
175 St. John Street
Quebec City, Quebec
G1R 1N4
Tel: (418) 643-4670

Dr. R. Deboo*
Director, Protection Branch
B.C. Ministry of Forests
1450 Government Street
Victoria, B.C.
V8W 3E7
Tel: (604) 387-5965

Mr. A. Deets
Mossbank Flying Service
Box 204
Mossbank, Saskatchewan
SOH 3G0
Tel: (306) 354-2580

Dr. J. M. Deschênes
Research Coordination Directorate
Research Branch
Agriculture Canada
Sir John Carling Bldg.
Ottawa, Ontario
K1A 0C5
Tel: (613) 995-7084

Mr. J.L. Dougans
Dougans Air Spray
10 - 2231 Albert Street
Regina, Saskatchewan
S4P 2V6
Tel: (306) 352-3517

Mr. W. Dredge
Lake Air Service Ltd.
Box 308
Lucky Lake, Saskatchewan
SOL 1Z0
Tel: (306) 858-2184

Dr. A.M. Drummond
Secretary, ACAFA
National Aeronautical Establishment
National Research Council of Canada
Ottawa, Ontario K1A 0R6
Tel: (613) 998-3567

Mr. Walter Dupin
Dupin Co. Ltd.
P.O. Box 4
Beatty, Saskatchewan
SOJ 0C0
Tel: (306) 752-3989

Mr. Roy Ellis
2799 Roblin Boulevard
Winnipeg, Manitoba
R3R 0B8
Tel: (204) 885-1500

Mr. C.J. Epp
CIBA-GEIGY Canada Ltd.
Agriculture Division
1401 Winnipeg Street
Regina, Saskatchewan
S4R 1K3
Tel: (306) 352-1001

Mr. Jim Falloon
Northern Air Applicators
Box 40
Smeaton, Saskatchewan
SOJ 2J0
Tel: (306) 426-2055

Mr. M. Feldman
Head, Structures & Mechanization
Engineering & Statistical Research
Institute
Research Branch, Agriculture Canada
Ottawa, Ontario K1A 0C6
Tel: (613) 995-3151

Mr. Richard Ferguson
Hoechst Canada Inc.
295 Henderson Drive
Regina, Saskatchewan
S4N 6C2
Tel: (306) 924-1500

Dr. R. J. Ford
Research Station
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan
S7N 0X2
Tel: (306) 343-8214

Mr. Brian Forman
Box 24
Spring Valley, Saskatchewan
S0H 3X0

Dr. Richard Frank
Agricultural Lab. Services
Ontario Min. of Agriculture & Food
University of Guelph
Bldg. 43, McGilvray Street
Guelph, Ontario N1G 2W1
Tel: (519) 824-4120

Dr. Claire A. Franklin
Chief, Pesticides Division
Environmental Health Centre
Health & Welfare Canada
Tunney's Pasture
Ottawa, Ontario K1A 0L2
Tel: (613) 593-6010

Mr. G. Gaboury*
Energy and Resources
Dept. of Lands and Forests
175 rue St. Jean
Quebec City, Quebec
G1R 1N4
Tel: (418) 643-4670

Monsieur Donald Gagnon
R.R. #3
Dunham, Quebec
J0E 1M0

Mr. L. Galvin
ABF/A
Aviation Regulation
Transport Canada
Place de Ville
Ottawa, Ontario
K1A 0NP
Tel: (613) 992-1927

Mr. Carl Gillis
Box 145
Gray, Saskatchewan
S0G 2A0
Tel: (306) 738-4416

Mr. James R. Graham
Box 1352
Kindersley, Saskatchewan
S0L 1S0
Tel: (306) 463-4870

Dr. G.W. Green
Canadian Forestry Service
Forest Pest Management Institute
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7
Tel: (705) 949-9461

Mr. P.W. Greening
Stinson-Eisler Adjustment Bureau
123 Pinehouse Drive
Saskatoon, Saskatchewan
S7K 5W1
Tel: (306) 933-1211

Dr. R. Grover
Research Station
Agriculture Canada
P.O. Box 440
Regina, Saskatchewan
S4P 3Z2
Tel: (306) 585-0255

Miss Gladys Hall
Research Station
Research Branch, Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan S7N 0X2
Tel: (306) 343-8214

Mr. & Mrs. A. Harbicht
Unity Air Spray
Box 95
Elrose, Saskatchewan
S0L 0Z0
Tel: (306) 378-2631

Mr. David Hardie
A&B Slater Aerial Applicators
Box 117
Alix, Alberta
T0C 0B0
Tel: (403) 747-2457

Mr. John Hare
Skyseeker Aircraft Corp. Ltd.
101 Brady Road
P.O. Box 243
Winnipeg, Manitoba
R3V 1L6
Tel: (204) 261-3330

Mr. Dan Harvey
Integrated Pest Management Specialist
Saskatchewan Agriculture
Walter Scott Building
3085 Albert Street
Regina, Saskatchewan S4S 0B1

Dr. J. R. Hay
Director
Research Station
Research Branch
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan S7N 0X2
Tel: (306) 343-8214

Mr. M. Hicks
Hicks and Lawrence Ltd.
P.O. Box 519
St. Thomas, Ontario
N5P 3V6
Tel: (519) 842-8786

Dr. Bernard D. Hill
Agriculture Canada
Research Station
Lethbridge, Alberta
T1J 4B1
Tel: (403) 327-4561

Mr. I. Hirsch
Operations Manager
Chimavir Aviation Services
46 100 HERZLIA Airport
Israel
Tel: 052-84096

Dr. J.E. Hollebone
Pesticies Division
Plant Health & Plant Products
Directorate
Agriculture Canada
Ottawa, Ontario K1A 0C6
Tel: (613) 995-7900

Mr. R.F. Hopkinson
Atmospheric Environment Service
Environment Canada
Regina Airport Terminal
P.O. Box 4080
Regina, Saskatchewan
S4P 3W5
Tel: (306) 359-5739

Mr. G. Hourjet
Oliver Chemical
818 48th Street
Saskatoon, Saskatchewan
S7K 3Y4
Tel: (306) 931-7771

Mrs. Martha J.K. Howey
Engineering & Statistical Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario K1A 0C6
Tel: (613) 995-5179

Mr. Roy Hrabats
Director
Aerial Application Program
Lakeland College
Vermilion, Alberta
T0B 4M0
Tel: (403) 853-2971

Mr. D. Hughes
Chipman Inc.
2108 C St. George Avenue
Saskatoon, Saskatchewan
S7M 0K7

Mr. M. Hussain
Alberta Agriculture
7000 - 113 Street
Edmonton, Alberta
T6H 5T6
Tel: (403) 427-4438

Mr. A. Irvine
Elanco
15 Innovation Boulevard
Saskatoon, Saskatchewan
Tel: (306) 343-9502

Mr. H.J. Irving*
Managing Director
Forest Protection Ltd.
P.O. Box 1030
Fredericton, N.B.
E3B 5C3
Tel: (506) 357-3366

Mr. John Iverson
P.O. Box 173
Meota, Saskatchewan
S0M 1X0
Tel: (306) 892-2168

Mr. T. Jansen
Alpine Helicopters
165 George Craig Blvd. N.E.
Calgary International Airport
Calgary, Alberta
T2E 7H3
Tel: (403) 277-0738

Mr. G.R. Josse
Cyanamid Canada Inc.
22 - 303 Saguenay Drive
Saskatoon, Saskatchewan
S7K 5R2
Tel: (306) 934-2406

Mr. W.F. Keith
Quikway Aviation
Box 1780
Brooks, Alberta
T0J 0J0
Tel: (403) 362-5731

Mr. Brent Kennedy
Hoechst Canada Inc.
295 Henderson Drive
Regina, Saskatchewan
S4N 6C2
Tel: (306) 924-1500

Dr. N.Y. Khan
Pacific & Freshwater Fisheries
Fisheries & Oceans Canada
240 Sparks Street
Ottawa, Ontario
K1A 0E6
Tel: (613) 995-4010

Mr. Maher Khouzam
Airworthiness Manual Project Group
Transport Canada
Tower B, Place de Ville
Ottawa, Ontario
K1A 0N8
Tel: (613) 593-5117

Mr. Darel Kilford
Prairie Aerial Applicators
8 Sunset Drive
Regina, Saskatchewan
S4S 2R5
Tel: (306) 585-0393

Mr. Tom Kinniburgh
Kinniburgh Spray Services
Purple Springs, Alberta
T0K 1X0
Tel: (403) 223-8245

Mr. Scott Kinniburgh
Kinniburgh Spray Services
Purple Springs, Alberta
T0K 1X0
Tel: (403) 223-8245

Mr. D. Knox
President
Assiniboia Flying Service Ltd.
Box 129
Mazenod, Saskatchewan S0H 2Y0
Tel: (306) 354-7744

Mr. Lee Kristjanson
Kristjanson Aviation Ltd.
Box 376
Foam Lake, Saskatchewan
S0A 1A0
Tel: (306) 272-4831

Professor D. Kristmanson
Dept. of Chemical Engineering
University of New Brunswick
P.O. Box 4400
Fredericton, N.B. E3B 5A3
Tel: (506) 453-4520

Mr. R.J. Labun
CIBA-CEIGY Canada Ltd.
Agriculture Division
1401 Winnipeg Street
Regina, Saskatchewan
S4R 1K3
Tel: (306) 352-1001

Mr. Gerald Larochelle
Box 840
Gravelbourg, Saskatchewan
S0H 1X0

Mr. A. Lavers
Shell Research Ltd.
Sittingbourne Research Centre
Sittingbourne, Kent
United Kingdom

Dr. F.J. LeRoux
Assistant Deputy Minister, Research
Agriculture Canada
Ottawa, Ontario
K1A 0C5
Tel: (613) 995-7084

Mr. Roy Lincoln
Research Station
Research Branch, Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan
S7N 0X2
Tel: (306) 343-8214

Dr. G. M. Lindberg
Director
National Aeronautical Establishment
National Research Council
Ottawa, Ontario K1A 0R6
Tel: (613) 993-0141

Mr. W. Lobay
638 Romaniak Road
Edmonton, Alberta
T6R 1A6
Tel: (403) 438-6176

Mr. W.C.E. Loftus
Chairman, ACAFA
P.O. Box 669
7 Edward Street
Manotick, Ontario
K0A 2N0
Tel: (613) 692-2134

Mr. Gary Lynchuk
Cupworth
Saskatchewan
S0K 1B0
Tel: (306) 256-3987

Mr. Carl E. Lynn
Information Officer
Research Station
Agriculture Canada
107 Science Crescent
Saskatoon, Saskatchewan
S7N 0X2
Tel: (306) 343-8214

Dr. A.R. Mack
Agrometeorology Section
Land Resource Research Institute
Research Branch
Agriculture Canada
Ottawa, Ontario K1A 0C6
Tel: (613) 995-5011

Ms. Monique M. Mackasey
Dow Chemical Canada Inc.
199 North Leonard Street
Regina, Saskatchewan
S4N 5X5
Tel: (306) 545-2777

Ms. Donna MacKenzie
BASF Canada Inc.
10 Constellation Court
Rexdale, Ontario
M9W 1K1
Tel: (416) 675-3611

Mr. Barrie Madu
Conair Aviation Ltd.
Box 220
Abbotsford, B.C.
V2S 4N9
Tel: (604) 853-1171

Mr. Edward J. Makowski
Hoechst Canada Inc.
295 Henderson Drive
Regina, Saskatchewan
S4N 6C2
Tel: (306) 924-1500

Mr. K.B. Marsden
Conair Aviation Ltd.
P.O. Box 220
Abbotsford, B.C. V2S 4N9
Tel: (604) 853-1171

Dr. J. Maybank
Director, Environment Section
Saskatchewan Research Council
30 Campus Drive
Saskatoon, Saskatchewan
S7N 0X1
Tel: (306) 664-5417

Mr. Duane McCartney
Research Station
Research Branch
Agriculture Canada
Melfort, Saskatchewan
S0E 1A0
Tel: (306) 752-2776

Prof. F.L. McEwen
A/Associate Dean
Ontario Agricultural College
University of Guelph
Guelph, Ontario
N1G 2W1
Tel: (519) 824-4120 (Ext.2284)

Ms. Janet McLean-Mueller
Pesticide Chemicals Branch
Alberta Environment
9820 - 106th Street
Edmonton, Alberta
T5K 0J6
Tel: (403) 427-5855

Mr. B. McLennan
CIBA-GEIGY Canada Ltd.
Agriculture Division
1401 Winnipeg Street
Regina, Saskatchewan
S4R 1K3
Tel: (306) 352-1001

Mr. Jack Melson
Aviation Safety Engineering
Transport Canada
Bldg. U-100, NRC Compound
Uplands Airport
Ottawa, Ontario
K1A 0N8
Tel: (613) 998-3425

Mr. Keith Mennie
P.O. Box 187
Gravelbourg, Saskatchewan
S0H 1X0

Dr. D.R. Menzies
Director
Research Station
Agriculture Canada
Vineland, Ontario
L0R 2E0
Tel: (416) 562-4113

Mr. John F. Mew
Airworthiness Manual Project Group
Transport Canada
Tower B, Place de Ville
Ottawa, Ontario
K1A 0N8
Tel: (613) 593-5117

Mr. E. Miller
Foothills Flying Service Ltd.
Box 927
Okotoks, Alberta
T0L 1T0
Tel: (403) 938-7605

Mr. Pierre Mineau
Canadian Wildlife Service
National Wildlife Research Centre
Environment Canada
Ottawa, Ontario K1A 0E7
Tel: (819) 997-1410

Mr. Gary Moffat
Oliver Chemical
236 - 36 Street North
Lethbridge, Alberta
T1H 3Z7
Tel: (403) 327-1571

Mr. D. Montgomery
Box 92
Morse, Saskatchewan
SOH 3CO

Mr. T. Nelson
Foothills Flying Services Ltd.
R.R. #2
High River, Alberta
TOL 1BO
Tel: (403) 652-3492

Mr. D. Neufeld
D. Neufeld Consulting & Research
Box 7707
Saskatoon, Saskatchewan
S7K 4R4
Tel: (306) 283-4695

Mr. W.C. Nyman
Bank City Aviation Ltd.
Box 1089
Moose Jaw, Saskatchewan
S6H 4P8
Tel: (306) 692-7335

Mr. Wayne D. Obrigewitsch
J.W. Wells Aero
C12 Glen Elm Trailer Court
Regina, Saskatchewan
Tel: (306) 337-6037

Mr. Marvin Omoth
Marvin's Spraying
Milestone, Saskatchewan
SOG 3LO
Tel: (306) 436-4509

Mr. John J. Onderdonk
Manager, Agricultural and
  Industrial Chemicals Section
Ontario Ministry of the Environment
Suite 100
135 St. Clair Avenue West
Toronto, Ontario M4V 1P5
Tel: (416) 965-2401

Mr. B. Panneton
Aerial Spray Engineer
c/o Institute of Aerospace Studies
University of Toronto
4925 Dufferin Street
Downsview, Ontario M3H 5T6
Tel: (416) 667-7717

Dr. N. Payne
Canadian Forestry Service
Forest Pest Management Institute
P.O. Box 490
Sault Ste. Marie, Ontario
P6A 5M7

Mr. D. Peck
Flight Services Directorate
Transport Canada
58 Service Road
Ottawa International Airport
Ottawa, Ontario K1V 9B2
Tel: (613) 998-4363

Mr. M. Pelletier*
Energy and Resources
Dept. of Lands and Forests
175 rue St. Jean
Quebec City, Quebec
G1R 1N4
Tel: (418) 643-4670

Mr. John G. Percy
Ministry of the Environment
Government of Ontario
Box 927
Caledonia, Ontario NOA 1AO

Mr. Robin D. Petersen
P.O. Box 1107
Battleford, Saskatchewan
SOM OEO
Tel: (306) 978-0269

Mr. Glenn Peterson
Box 25
Cardross, Saskatchewan
SOH OPO
Tel: (306) 475-2810

Mr. L.K. Peterson
Pesticide Chemicals Branch
Alberta Environment
Oxbridge Place
9820 - 106 Street
Edmonton, Alberta T5K 2J6
Tel: (403) 427-5855

Mr. Terrell Piquet
Parkside Aerial Applicators
Box 745
Shellbrook, Saskatchewan
SOJ 2E0
Tel: (306) 747-2309

Mr. K.W. Plews
Manitoba Dept. of Environment
Box 7, Bld. #2
139 Tuxedo Avenue
Winnipeg, Manitoba
R3N 0H6
Tel: (204) 944-7067

Mr. Keith Price
Plant Industry Division
Alberta Agriculture
7000 - 113th Street
Edmonton, Alberta
T6H 5T6
Tel: (403) 427-5330

Mr. Paul Pytel
Skyseeker Aircraft Corp. Ltd.
101 Brady Road
P.O. Box 243
Winnipeg, Manitoba
R3V 1L6
Tel: (204) 261-3330

Prof. W.B. Reed
Dept. of Agricultural Engineering
Unversity of Saskatchewan
Saskatoon, Saskatchewan
S7N 0W0
Tel: (306) 343-3191

Mr. Jacques René de Cotret
Vice-president and Director
Aviation Service
Gérard Parizeau Ltée
410 rue Saint-Nicolas
Montreal, Quebec H2Y 2R1
Tel: (514) 282-1112

Mr. R. Barry Rogers
Rogers Engineering Inc.
1510 Hilliard Street East
Saskatoon, Saskatchewan
S7J 0G4
Tel: (306) 477-2667

Mr. T. Sasayama
Sumitomo Chemical America Inc.
345 Park Avenue
New York, N.Y. 10154
U.S.A.
Tel: (212) 207-0600

Mr. Terrence Satens
Agro Air Spray
Box 58
Foam Lake, Saskatchewan
SOA 1A0
Tel: (306) 272-4559

Mr. Ken Scheske
Box 250
Russell, Manitoba
ROJ 1W0
Tel: (204) 773-2878

Mr. Jim Schick
Spring Valley
Saskatchewan
SOH 3X0

Mr. Joseph Schmit
President
Saskatchewan Agric. Aviation Assoc.
Box 494
Davidson, Saskatchewan
SOG 1A0
Tel: (306) 567-4313

Mr. Tom Seaborn
Field Services
Alberta Agriculture
Courier Box #1
P.O. Box 1870
Provincial Building
Rocky Mountain House, Alberta
TOM 1TO

Dr. G. Shaw
Canadian Wildlife Service
Environment Canada
Room 1000
9942 - 108 Street
Edmonton, Alberta T5K 2J5
Tel: (403) 435-7355

Smokey-Burn Ag Air
Box 183
Carrot River, Saskatchewan
SOE OLO

Mr. T.W. Spence
Bonnyville Air Services (1980) Ltd.
Box 2499
Bonnyville, Alberta
TOA OLO
Tel: (403) 826-6885

Mr. Allan Spreeman
A&B Slater Aerial Applicators
Box 303
Olds, Alberta
TOM 1PO
Tel: (403) 335-3714

Mr. Malcolm Stewart
Herbicide Evaluation Officer
Pesticides Division
Plant Health & Plant Products Directorate
Food Production & Inspection Branch
Agriculture Canada
Ottawa, Ontario K1A OC6
Tel: (613) 995-7900

Dr. W.E. Stewart
Evaluation Officer
Pesticides Division
Plant Health & Plant Products
Directorate
Agriculture Canada
Ottawa, Ontario K1A OC6
Tel: (613) 995-7900

Mr. W. Stonehouse
Chipman Inc.
P.O. Box 9910
Stoney Creek, Ontario
L8G 3Z1
Tel: (416) 643-4123

Mr. J.R. Stoneouse
Stoneouse Aviation Ltd.
Box 862
Eston, Saskatchewan
SOL 1A0
Tel: (306) 962-4748

Mr. D.R. Strilchuk
Hoechst Canada
295 Henderson Drive
Regina, Saskatchewan
S4N 6C2
Tel: (306) 924-1500

Mr. Roland St. Jean
Ministère de l'Environment
3900 rue Marly
Ste-Foy, Québec
Tel: (418) 644-6598

Mr. Derek Tasehsel
Quikway Aviation Ltd.
Box 1780
Brooks, Alberta
TOJ OZO
Tel: (403) 362-5731

Mr. Norman Thomas
Thomas Air Spray Ltd.
Box 94
Vanscoy, Saskatchewan
S0L 3J0
Tel: (306) 668-4513

Mr. Derek Turner
Box 100
Wakaw, Saskatchewan
S0K 4P0
Tel: (306) 233-5139

Mr. K. Usui
Sumitomo Chemical America Inc.
345 Park Avenue
New York, N.Y. 10154
U.S.A.
Tel: (212) 207-0600

Mr. J. Vaasji
Bi-Air Application Services
5707 - 29th Street
Lloydminster, Alberta
T9V 1Y1
Tel: (403) 875-2612

Mr. J. A. Varjassy
Prairie Aerial Applicators Ltd.
8 Sunset Drive
Regina, Saskatchewan
S4S 2R5
Tel: (306) 585-0393

Dr. W. Varty*
Maritime Forest Research Centre
Box 4000
Fredericton, New Brunswick
E3B 5P7
Tel: (506) 452-3500

Mr. P.W. Voisey
Director, Engineering & Statistical Research Institute
Research Branch
Agriculture Canada
Ottawa, Ontario K1A 0C6
Tel: (613) 995-5179

Mr. S. Waker
Smith Air (1976) Ltd.
Box 1414
Swift Current, Saskatchewan
S9H 3X5
Tel: (306) 773-4219

Mr. Dale Weisbrot
Saskatchewan Agriculture
3085 Albert Street
Regina, Saskatchewan
S4S 0B1
Tel: (306) 565-4667

Mr. G. Dale Wiberg
Weyburn Flying Services Ltd.
P.O. Box 54
Weyburn, Saskatchewan
S4H 2J8
Tel: (306) 842-7979

Mr. R.H. Wickens
National Aeronautical Establishment
National Research Council
Bldg. M-2, Montreal Road
Ottawa, Ontario
K1A 0R6
Tel: (613) 993-0566

Mr. E. Wiens
Prairie Agricultural Machinery Institute
c/o L.C.C. Campus
Lethbridge, Alberta
T1K 1L6
Tel: (403) 329-1212

Mr. A.D. Wood*
Flight Research Laboratory
National Aeronautical Establishment
National Research Council
Ottawa, Ontario K1A 0R6
Tel: (613) 998-3180

Mr. W. Yarish
Alberta Agriculture
7000 - 113 Street
Edmonton, Alberta
T6H 5T6
Tel: (403) 427-5329

Professor W.E. Yates
Department of Agricultural Engineering
University of California
Davis, California 95616
U.S.A.
Tel: (916) 752-0474

Mr. A. Yaworski
Saskatchewan Agric. Aviation Assoc.
Box 130
Viscount, Saskatchewan
S0K 4M0
Tel: (306) 944-4520

Dr. K. Yoshida
Saskatchewan Research Council
30 Campus Drive
Saskatoon, Saskatchewan
S7N 0X1
Tel: (306) 664-5436

Mrs. Mardy Zazelenchuk
Box 2065
Kamsack, Saskatchewan
S0A 1S0

---

*ACAFA Members who did not attend the Symposium.